IMPACT OF IMPROVED DAYLIGHTING ON URBAN DOMESTIC & COMMERCIAL ELECTRICITY CONSUMPTION

FINAL REPORT

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Contents

Section Page No.

I. Introduction 1

II. Importance of Daylighting 4

III. Theory 6

IV. Review of literature on Daylighting 13

V. Design for Daylighting 22

VI. The Field Study 28

VII. The Computer Aided Method of Design 39

VIII. Heat Gain Through Fenestration 45

IX. Daylighting and Electricity Consumption 49

X. Conclusions and Suggestions 54

References

Appendix-1

Appendix-2

List of Tables

Table 1 - Illumination Requirement for Interiors

Table 2 - Values for Constant 'C'

Table 3 - Apartment Selected for Study in Delhi

Table 4 - Number of households and their daylight factors in Delhi

Table 5 - Potential reduction in electricity consumption for changes in daylight factors

Table 6 - Potential reductions possible in electricity consumption by improving daylight factos

Table 7 - Apartment Selected for Study in Bangalore

Table 8 - Number of households and their daylight factors in Bangalore

List of Figures

Fig. 1 - Estimates of lighting load for South Bombay

Fig. 2 - The hemispherical sky

Fig. 3 - The split flux principle for internally reflected component of daylight factor

Fig. 4 - Illumination from uniform sky

Fig. 5 - Lux-grid 1 - For daylighting design of windows in the absence of external obstruction

Fig. 6 - Lux-grid 2 - For daylighting design of windows in presence of external obstruction.

Fig. 7 - Daylight factors on the workplane for a centrally located window

Fig. 8 - Daylight factor on the workplane for a corner located window

Fig 9 - Penetration of sky component

Fig. 10 - Lateral spread of sky component

Fig. 11 - Variation of the penetration and spread of sky component with sill height above the working plane

Fig. 12 - External horizontal illumination due to clear sky excluding direct sunlight.

Fig. 13 - Variation in internal illumination for different DF percentages. For a typical summer month.

Fig 14 - Variation in internal illumination for different DF percentages. For a typical winter month.

Fig 15 - CBRI Design curve and the fitted curve

Fig. 16 - Flow cart of the computer program.

Fig. 17 - Nomogrph for daylighting and supplemented lighting design of buildings.

I. INTRODUCTION

The primary purpose of light and lighting is to provide illumination for the performance of various visual task with a maximum of speed, accuracy ease and comfort and a minimum of strain and fatigue. The requirement of lighting for various cases at different times of the day is met by a mix of daylighting and artificial lighting, depending on availability of daylighting. lighting is required by households, offices, commercial establishments, shops as well as the large and small industries.

Lighting design requires adequate provision of daylighting and artificial lighting depending on the type of building and the nature of visual task to be executed by the occupants Prevalent sky condition in India ensures adequate daylighting for most of the working hours (1). But the use of daylighting while reduces the need of artificial lighting, increases the requirement of energy for space conditioning, depending on the season. There is a tradeoff involved in the use of daylighting and this is one of the reasons commonly given to reduce daylight by artificial means such as curtains, and take recourse to additional lighting from artificial lighting.

There exist no official figures for electricity consumption by lighting from various consumer categories, such as domestic, commercial, and industries However, surveys carried out by TERI in Delhi in 1988 indicate that electricity consumed for lighting is of the order of 60-80 percent of total electricity consumed by households, in summer and 25-45 percent in winter. A survey of domestic and commercial consumers in South Bombay in 1986 showed that electric lighting accounted for 37 percent of the total electricity consumed. Estimates of lighting load

for South Bombay sample is given in fig. 1.

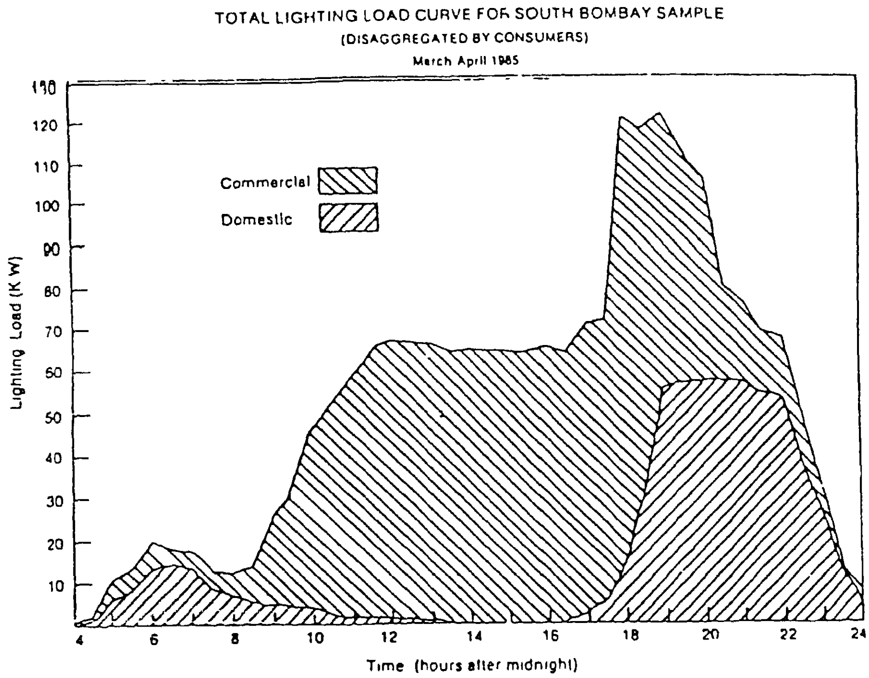


Fig.1 Estimates of lighting load for South Bombay

It is seen that while domestic consumption for lighting takes place in the evening hours, a major share of commercial consumption (in offices) is during the daytime hours and the demand from from shops and markets occurs in the evening. Hence, while reduced use of lighting in commercial sector would lead to an overall reduction in energy consumption, a reduction in the lighting demand from the domestic sector would assist in reducing the demand during the system peak hours.

It is in this context that this study is conceived and has the following objectives:

1. To review the various methods available and used for daylighting design.
2. To conduct field study in households and offices in two major cities to see how far these design methods are used in the field
3. To bring out more efficient and practical methods and guide lines for design of fenestration for better daylighting.
4. To study the impact of improved daylighting on domestic and commercial electricity consumption

- This study brings out a detailed review of the work done in India and abroad in this field.
- The design methods suggested by CBRI (accepted by the Bureau of Indian Standards) and the extent to which it is applied in the field are analyzed.
- A computer aided method, which is much easier to handle compared to the CBRI design charts, is proposed.
- The impact of improved daylighting on domestic and commercial electricity consumption is also looked into.
- Some suggestions are included as guidelines for improving the use of day light in the actual practice.

II. IMPORTANCE OF DAYLIGHTING

Daylight is a natural source of light which meets all requirements of good lighting For ages human eye has been adapted to environment produced by daylight. Under clear sky conditions in India, plentiful daylight is available outdoors which can be used for interior illumination by the proper designing of windows. Still, reduction of thermal performance of the building envelope, sudden variations in illumination, glare problem etc. are some major problems in daylighting. Especially because of reduction of thermal performance it is practically impossible to illuminate the modern buildings exclusively by daylight but with proper sizing and location of windows it is possible to make at least the general lighting by natural means.

While illumination levels for different tasks are specified by the Bureau of Indian Standards (see Table 1), the method to be adopted to get the required level of illumination by a combination of daylight and artificial lighting is left to the user. It is generally found that the user prefers to adopt the easier route of going by way of artificial lighting, since it is more convenient.

But the most important benefit of application of natural lighting is the increased occupant satisfaction. The related benefits would be reduced electricity consumption

Table 1 : Illumination Requirement for Interiors
(Indian Standard Code of Practice IS: 2440-1975)

S.No	Location	Illumination (Lux)
1.	Dwellings	
	Kitchen	200
	Study	150
2.	Schools	
	Class room	150
	Lecture theatre	150 to 200
	Study hall	150 to 200
	Laboratory	150 to 300
3.	Offices	
	General	150
	Drawing	300
	Enquiry	50 to 150
4.	Hospitals	
	General wards	100
	Pathological laboratory	200 to 300
5.	Libraries	
	Stack room	70 to 150
	Reading room	150 to 300
	Counter area	200 to 300
	Catalogue room	150 to 200

III. THEORY

Good daylighting design requires careful study of all factors like daylight availability and its variation from time to time, sky illuminance and its variation, room dimensions, window locations and interior reflection coefficients and brightness balance between adjacent areas in visual field

Studies on day lighting deal separately with the two aspects of interior daylighting viz. the sky component and the reflected component. Often the concept of daylight factor is made use of in specifying the interior illumination. Daylight factor is the sum of sky and reflected components expressed as a percentage of external illumination (excluding direct sunlight).

Design sky: Seasonal and daily variations of daylight make the problem of daylight design very complicated. To fulfill the need for unfailing supply of daylight indoors for most of the working hours in a day, a design sky has been proposed for India, which has since been accepted by Bureau of Indian Standards.

During the winter months of 1963 and 1964 measurements were carried out (1) on the illuminance distribution of the clear blue sky over most of the principal cities of India. Simultaneous observations were also made on the amount of diffused illumination on a horizontal surface. It was found that for the clear sky, the illumination distribution followed a simple pattern especially when the sun was at low altitudes. It was also observed that the minimum sky luminance Lm was related to the diffused illumination by the following equation.

$$\frac{L_m}{D} = 0.6 \qquad [1]$$

These conditions led to the formulation of a design sky for the use in daylighting design of buildings in tropics. Since normal working hours commence around 8 a.m., a design based on a solar altitude of 15o in the sky should be adequate (1). The clear design sky basis holds good for any orientation of the building and ensures adequate day-lighting indoors for 90% of the day time working hours.

The illumination on a horizontal plane outdoors due to the entire sky at the design sky condition is 8000 lux and that due to the sky and the sun is 16,000 lux.

Brightness distribution of clear design sky: The brightness at an angle above the horizon is given by the expression.

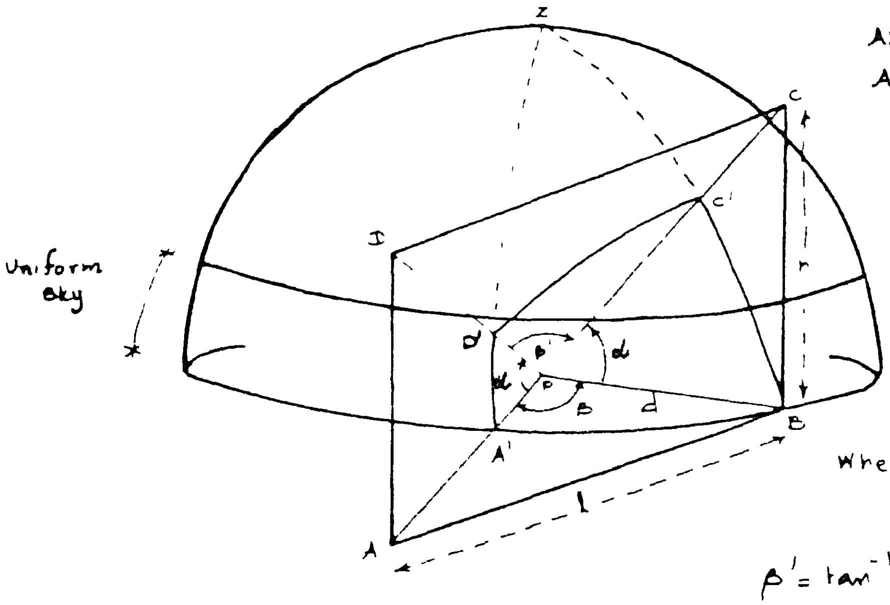
$$\beta = \beta_z Cosec\theta \quad for\ \theta\ between\ 15^0 \& 90^0 \qquad [2a]$$

$$\beta = Constant \quad for\ \theta\ between\ 0^0 \& 15^0 \qquad [2b]$$

where β_z is the brightness at the zenith.

Sky component : The daylight factor consists of sky component, the internally reflected component and the externally reflected component. Sky component is defined as the ratio of that part of the daylighting illuminance at a point on a given place which received from a sky of known or assumed luminance distribution to the illumination on a horizontal plane due to the unobstructed hemisphere of this sky (excluding direct sunlight).

The Indian sky explained before can be fitted in Hopkinson basic theory (2) to get the required equations for illumination calculation. In Fig. 2, the sky has been shown as a hemisphere, with the reference point as centre and the distance of this point from the window as radius. Based on the values of B and a we have the following equations for computation of illumination level on a horizontal plane.



ABCD – window
A'BC'D' – portion of sky as seen from pt 'P' through the window

Where $\beta = \tan^{-1}(l/d)$

$\alpha = \tan^{-1}(h/d)$

$\beta' = \tan^{-1}(\tan\beta \cos\alpha)$

$\alpha' = \tan^{-1}(\tan\alpha \cos\beta)$

Fig.2 The Hemispherical design sky

(i) $\alpha > \pi/12 \, and \, \beta > \beta 1$

$$S_H = 0.191[-0.1294\beta 1 + Sin^{-1}(Sin\alpha . Sin\beta 1) + 1.932(\beta - \beta 1) - 1.932Cos(\beta' - \beta 1')] \quad [3a]$$

(ii) $\alpha > \pi/12 \, and \, \beta \leq \beta 1$

$$S_H = 0.191[-0.1294\beta + Sin^{-1}(Sin\alpha.Sin\beta)] \qquad [3b]$$

(iii) $\alpha \leq \pi/12$ β - any value

$$S_H = 0.369(\beta - \beta' cos\alpha) \qquad [3c]$$

where $Sin(\beta 1^1) = Sin\beta 1 Cos(\pi/12)$

$\beta 1 = Cos^{-1}(tan\pi/12.Cot\alpha)$

($\beta 1$ is that value of β for which $\alpha' = \pi/12$)

Internal reflected component: Natural lighting entering a room is reflected from the surface of the room. After multi-reflection the illuminance received at a point is known as the internally reflected component. It is defined as the ratio of that part of the daylight illumination at a point on a given plane which is received from internal reflected surfaces to the illumination on a horizontal plane due to an unobstructed hemispherical sky of known illumination distribution (again direct sun is excluded).

The general case of inter-reflection is considered as follows. An enclosure of total area A and uniform reflectance R receives certain flux The flux which is reflected initially is f and the flux after second reflection is fR. Thus the total flux after multi reflection is

$$F = f(1 + R + R^2 + - - - - -) = \frac{f}{1 - R} \qquad [4]$$

(since R < 1).

From definition, the luminance of a surface (L) is given by L = F/A

Hence, L will be equal to

$$f/A * (1 - R) \qquad [5]$$

The Building Research Station UK has proposed the split flux principle (3) for the calculation of internally reflected components (fig.3). The flux entering the window is divided into two parts.

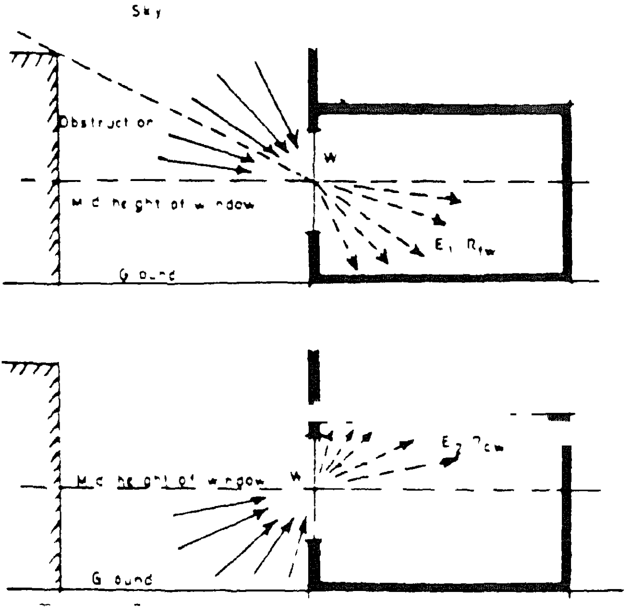


Fig.3 Split flux principle for internally reflected component of daylight factor

1. The flux coming from sky or reflected from an obstruction enters into the room below mid height of the window.
2. The flux reflected from the ground enters the room above mid height.

Thus, the value of f in eq (5) will be equal to

$$T.W.(E_1 R_{fw} + E_2 R_{cw})$$

where T - light transmission of window glass

W - window area

E1, E2- Illuminance on plane of windows above and below the horizontal respectively,

Rfw and Rcw are the reflectance of floor and ceiling of the room respectively.

For clear sky condition assumed for Indian conditions the equation for internal reflected illumination gets simplified to

$$\frac{0.85W}{A(1-R)}(CR_{fw} + 10R_{cw}) \qquad [6]$$

Table 2: Value for "C" for different angles of obstruction

Angle of obstruction from centre of window	C Overcast Sky	C Uniform Sky
0	39	50
10	35	42
20	31	35
30	25	27
40	20	21
50	14	16
60	10	11

C is a constant denoting the function of the flux entering the room from above the mid-height of the window and includes the flux directly from the visible sky and from the surface of obstruction. Values of constant 'C' for different angles of obstruction is given in Table (2).

Externally reflected component: The external reflected component of the daylight factor is due to the reflected light from obstructions outside the window. The reflected light depends on reflectance of the surface of the obstruction. In general, it is assumed that the luminance of an external obstruction is about one tenth of the average sky illuminance.

IV. REVIEW OF LITERATURE ON DAYLIGHTING

For daylighting in buildings located in tropical area, it is proposed that the theoretical sky be based on a solar altitude of 15o. This corresponds to a period of 1-1/2 hr. after sunrise and 1-1/2 hr. before the sunset. The brightness distribution of the above sky is expressed by two equations.

$\beta_\theta = \beta_z Cosec\theta$ for θ between $15^0 \& 90^0$

$\beta_\theta =$ Constant for $\theta \leq 15^0$

where β_z is the brightness at Zenith.

Indian Standard for daylighting (IS 2440) has accepted this design

sky

Building Research Station, U.K (4) has developed daylight protractors for daylight prediction inside the rooms. The sky and external reflected components are found out using the protector and the IRC (Internal Reflected Component) is estimated using a set of nomogram called B.R.S nomograms.

B.R.S has also developed slide rules for the calculation daylight factors for side-lit rooms. This method is not very accurate but useful for practical purpose.

In Hopkinson's theory (2), the over cast sky is taken as a perfect diffuser. Considering a hemisphere of uniform brightness of radius R, the illumination of the centre from any part of the hemisphere will be proportional to $1/R^2$. From fig (4) an elemental ring of angular width "$d\theta$" of the hemisphere at an elevation "θ" above the horizon will have an area $Rd\theta * 2\pi R*Cos\theta$ If the uniform brightness

of the sky is assumed to be B, The illumination at the centre is given by

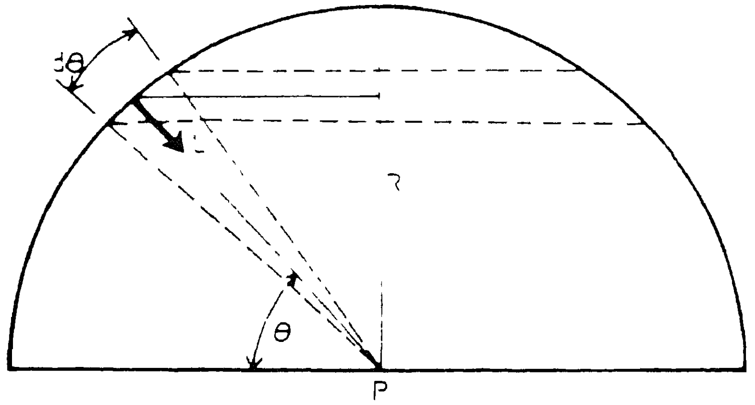


Fig.4 Illuminance from uniform sky

$$dE = B * 2\pi \, Sin\theta Cos\theta \, d\theta \qquad [7a]$$

$$E = \pi B \qquad [7b]$$

The same procedure can be applied to determine the illumination from a small part of the sky seen through the window. BRS daylight tables (similar to the IS 2440 tables) is developed based on this theory. Tables are prepared for sky of both uniform brightness and overcast.

The solid angle projection principle explained in ref. (2) is another alternate approach to determine sky factor. This method is applicable for irregular

shapes of windows and other sources of lights.

Following are the codes of practice recommended in India.

1. National building code of India - 1983
2. IS 2440 - 1976 "Guide for daylighting of buildings."
3. IS 7942 - 1976 - "Code of practice for daylighting of educational buildings"
4. IS 6060 - 1971 "Code of practice for daylighting of factory buildings "
5. IS 3646 (part I) - 1966 "Code of practice for interior illumination (Principles of good lighting and aspects of design) etc.

These codes deal with design methods for provisions of daylighting, artificial lighting and supplementary artificial lighting depending up on the type of buildings and the nature of the visual tasks.

Based on Hopkinson's theory Narasimhan and Saxena (6) have developed equations for the computation of sky component. Same equations are made use of in developing the tables presented in IS 2440 The angular dimension of any such window element of length 'l' and height 'h' are expressed as l/d and h/d for any point at a normal distance d from the external surface of the window aperture.

From the projection of the given point on the window plane rectangles can be drawn so as to cover the entire window area. The contribution to sky component (SC) from the different rectangular areas with projected point as the corner can be determined from the tables against their l/d and h/d values. By suitable addition or subtraction of the contribution from these rectangular areas, the sky component from the given window can be determined.

The lux grid method explained in ref.(7) is similar to the pepper plot method given in ref. (2). Lux grid is a perspective of window wall comprising a grid of square elements in which the contribution of each element to daylight on a horizontal workplane is marked as dots, crosses and stars. A dot, a cross and a star represents 0.5, 1 and 2 lux respectively. The dimension of square elements is one-tenth of the distance of the given point from the window wall at which the illuminance is required. The base line WPW of the grid (fig. 5,6) represents the level of the workplane and the centre of P of the base line is the projection of the given point on to the window wall. Any window can be outlined to the scale on the grid with respect to the position of the given point. The summation of contribution of each element within the window outline gives the expected daylight at the given indoor point on horizontal workplane. Since the contribution of any part of window openings below the workplane is insignificant to the workplane illuminance, only the window openings above the base line of the lux grid need be outlined.

The lux grid method enables the estimation of daylight due to given windows as well as the design of windows for any desired illuminance on the workplane.

Muthukumar(9) has developed a computer program based on the equations presented in ref.(6) for the design of fenestration. He has also developed some simplified design graphs for the design of fenestration under Indian condition.

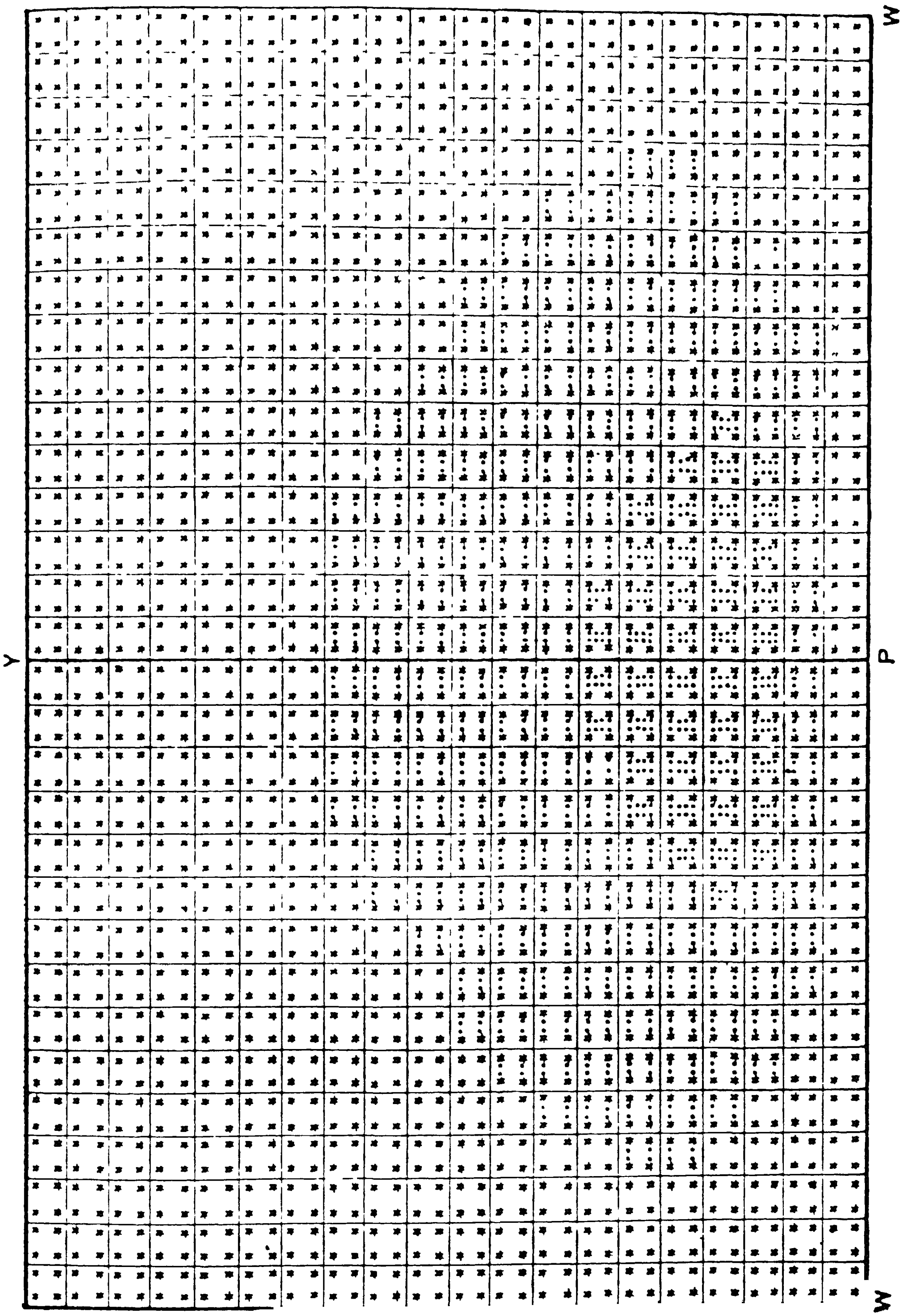
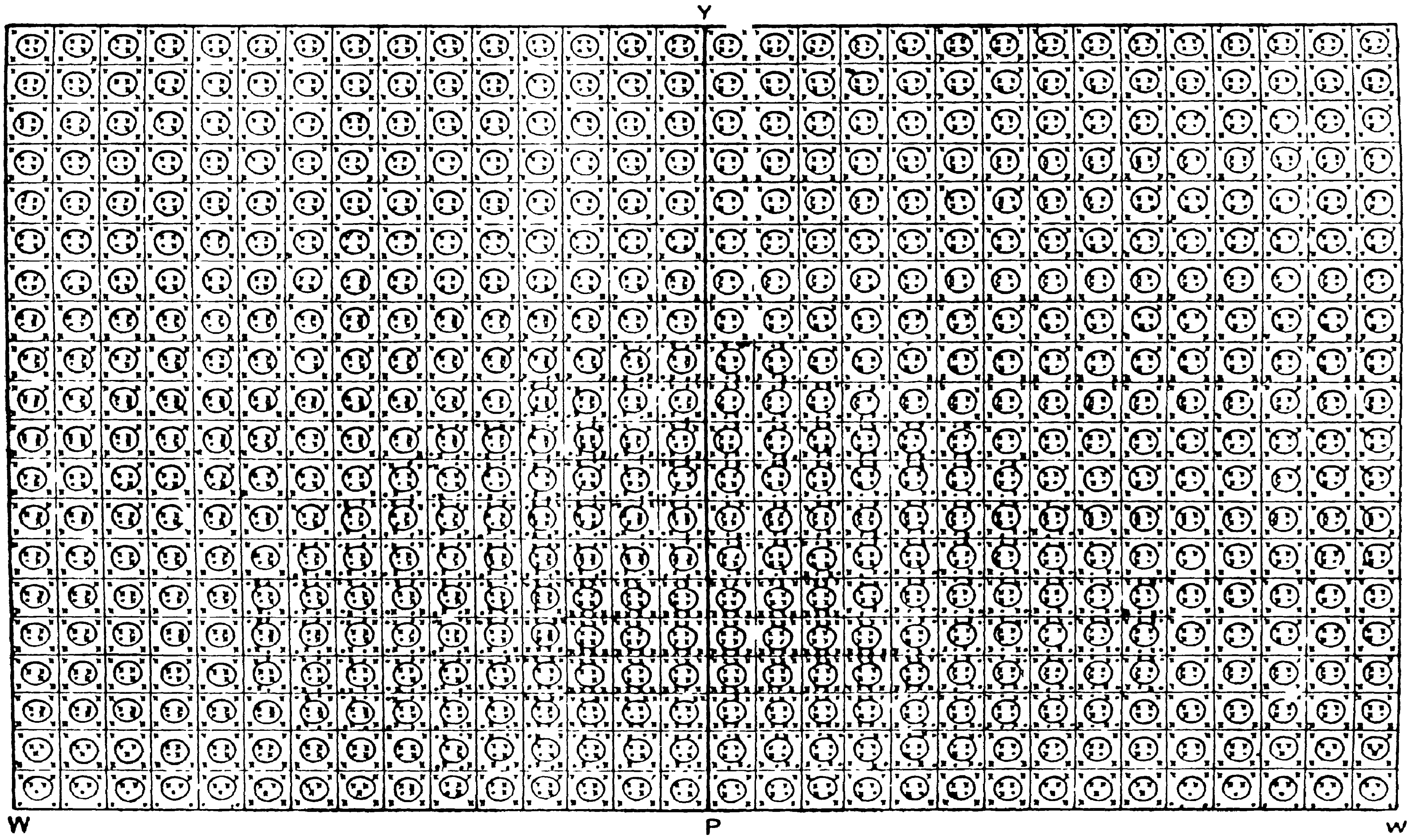


Fig.5 LUX-GRID I FOR DAYLIGHTING DESIGN OF WINDOWS IN ABSENCE OF EXTERNAL OBSTRUCTIONS

Fig.6 LUX-GRID II FOR DAYLIGHTING DESIGN OF WINDOWS IN PRESENCE OF EXTERNAL OBSTRUCTIONS



The technical proceedings of the 1983 International daylighting conference held in Phoenix Arizona U.S.A, February 16- 18 was published as Vol.6, Nos 2-4 of the Journal of Energy and Buildings (10). The papers published in Vol.6, No.2 address the issues of integrated daylighting design. Design concept, lighting control systems etc. are presented. Issue No.3 includes papers discussing an array of design tools including hand calculation methods and illumination calculation computer models. Issue No.4 completes the proceedings with a series of papers discussing energy performance issues. Some of the important findings pertaining to lighting are summarised below.

Cooper and Crisp (11) describe a small but detailed investigation aimed at identifying whether U.K. designers are attempting to use daylighting as a means of reducing fuel consumption when designing office accommodation. Data have been collected through a series of indepth, focused interviews conducted with memebers of selected, architectural and engineering practices. The contents of these interviews were analysed:

(a) to discover whether the designers interviewed tried to exploit natural light as a source for lighting their interiors;

(b) to discuss, if they did attempt to do so, whether they saw any barriers preventing or hindering them from exploiting that source; and

(c) to disclose, if designers chose not to exploit daylight, why they chose not to do so.

The results showed that at least three separate groupings could be identified amongst the U.K. designers interviewed with respect to their attitude to daylighting: (1) those who are pre- disposed to exploit daylight; (2) those who are

indifferent to daylighting as a pertinent issue in building design; (3) those who reject daylighting as a useful option for energy saving. For the last two of these groupings, solely the provision of daylight design aids - existing or subsequently improved - is not likely to extend the exploitation of daylighting for the purpose of producing energy-conscious buildings. A stage of education and demonstration is proposed to encourage these groups to reassess their objections to daylight design.

Gates and Wilcox (12) carried out a daylighting study of classrooms in three California climates was made using the DOE- 2.1B Building Energy Analysis Computer Program The daylighting configurations studied were unilateral, lerestory, and top- lighting designs The climates studied were Fresno, Oakland, and Mount Shasta.

It was found that daylighting could produce lighting energy savings in excess of 80%, and total building energy savings in excess of 30the less than optimum daylighting designs studied still used less energy than classrooms having no daylighting features.

Choi et. al (13) carried out a complete analysis of the cost- effectiveness of daylighting strategies should include the impact of daylighting on peak electrical demand as well as on energy consumption An hour-by-hour building energy analysis program to study the thermal and daylighting impacts of fenestration on peak demand was developed. Fenestration properties and lighting system characteristics were varied parametencally for office buildings in Madison WI and Lake Charles LA. Peak electrical demand was disaggregated by component and by zone, monthly patterns of peak demand were examined, and impacts of fenestration performance on chiller size were studied.

The results suggest that for daylighted office buildings, the peak elec-

trical demand results from a complex trade-off between cooling load due to fenestration parameters, lighting load reductions due to glazing and lighting system characteristics. Lowest peak demands generally occur with small to moderate size apertures. With daylighting, peak electrical demand is reduced by 10 to 20% for the building configuration studied (37% perimeter zone, 63% core zone). This work indicates that solar gain through order to realize the potential of daylighting to significantly reduce peak electrcial demand.

V. DESIGN FOR DAYLIGHTING

A good daylighting design requires careful study of all factors like daylight availability and its variation from time to time, sky illuminance and its variation, orientation of the facade, ground reflectance, room dimensions, window locations and interior reflection coefficients of different surfaces etc. However, there is some times a design problem that needs quick answer and the designer wants a very simple design aid. If some of the above design parameters are kept constant it is possible to develope a simplified approach.(8)

The following average conditions are assumed to arrive at a simple design method proposed by CBRI.

1. The window sashes are metallic or wooden, cutting off 10 or 30 per cent of the entering light respectively.
2. The windows are provided with glass panes of transmission coefficient 0.85.
3. The window has a horizontal louver at its top edge about 60 cm wide, cutting off 20 per cent of the expected daylight.
4. The glass panes have maintenance factor (depreciation due to dirt) of 0.85.
5. The window sill coincides with the work plane which is at a height of about 85 cm above the floor level.
6. The room interior has reflection coefficients of 0.8 for the ceiling, 0.5 for the walls and 0.3 for the floor surface with white wash, off-white and cement/terrazzo respectively.
7. Ceiling height is between 3.05 and 3.60 meters.

8. Height of obstruction in front of the window is less than one third of the distance of separation[1].

9. The ground opposite the window has a reflection coefficient equal to 0.25 which corresponds to the usual ground with grass, road or pavement, or combinations thereof.

Use fig. (7) and (8) which give daylight factors due to a centrally located and a corner located window respectively. There are three sets of curves viz. solid, broken and dotted The solid and broken curves refer to the daylight factors at room centre and the room rear respectively and the dotted curves refer to the average inter-reflected components. WL denotes the window on the long wall and Ws that on the short wall The abscissa relate to fenestrations expressed as percentage fraction of the floor area. The curves marked A are applicable to floor areas from 10 to 30 sq.m. and B from 30 to 60 sq.m. If the overall (gross) area of a fenestration is considered, the left hand ordinates indicate the daylight availability (as daylight factor) through the window with metallic or wooden sashes When the same opening percentages refer to net clear area (glazed or open) the right hand ordinates indicate the daylight availability.

For square or near square rooms, the mean of the results for short wall and long wall windows should be taken. Similarly, for distributed windows or a window in between central and corner position, the mean of the results for central and corner windows should be taken.(8)

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[1] Multiplication factors are provided for heights exceeding this limit

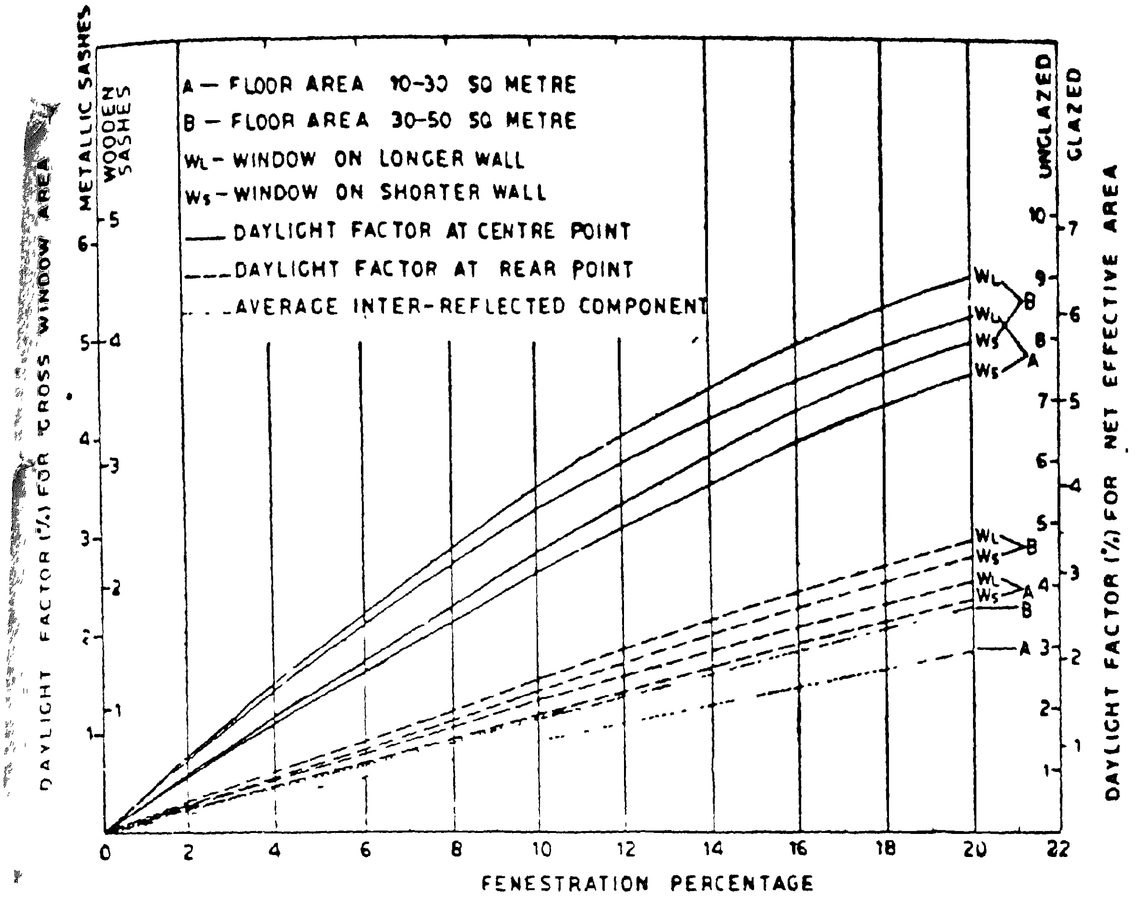


Fig.7 DAYLIGHT FACTORS ON THE WORK PLANE FOR A CENTRALLY LOCATED WINDOW

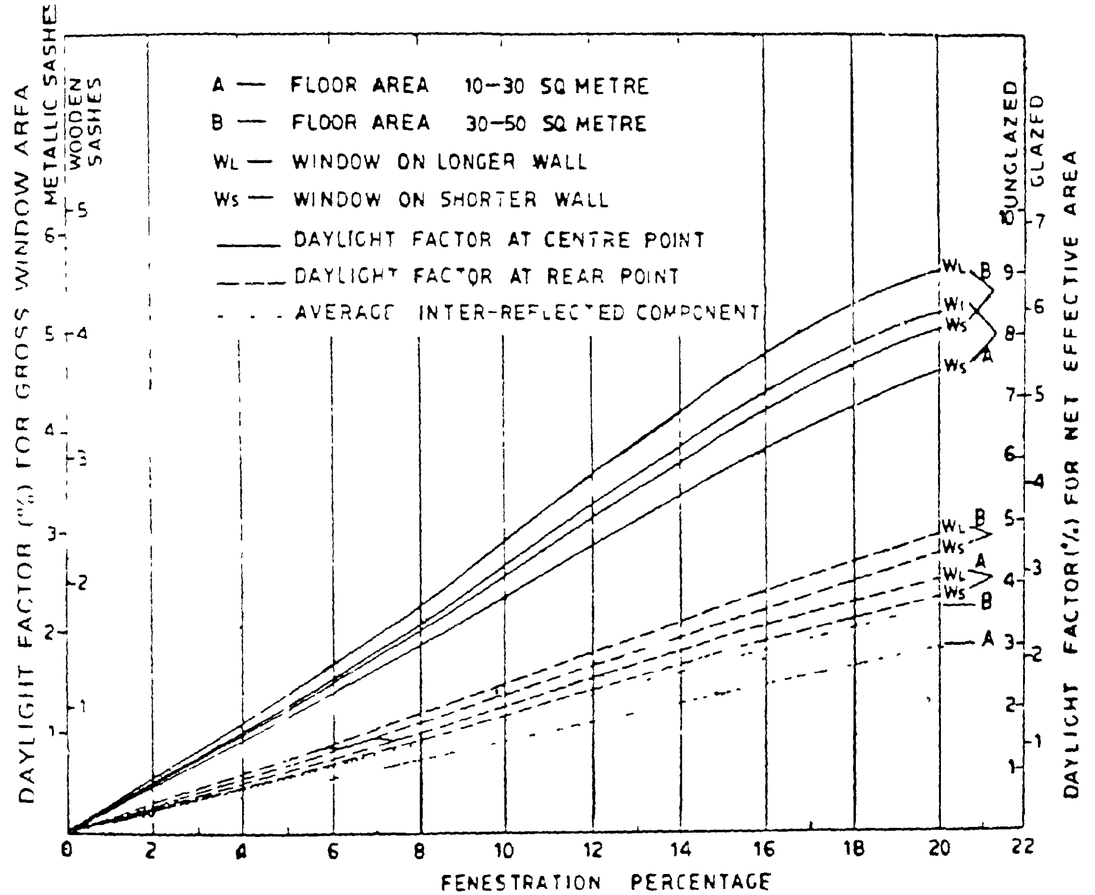


Fig.8 DAYLIGHT FACTORS ON THE WORK PLANE FOR A CORNER LOCATED WINDOW

After obtaining the window area as percentage of the floor area, actual window dimensions can be found For example a 10 per cent fenestration in a room having 40 sq.m. floor area would mean 4 sq.m. window area. This area can be had by several combinations of length and height. The penetration and spread of sky components for these fenestrations with metallic sashes are obtainable from Fig. (9) and (10). For wooden sashes the values should be reduced by a factor 0.8. If one assumes the window length as 2.7 m. and height 1.5 m, choosing the set of curves for 1.5 m.ht (for metallic window). We find that a 2 per cent sky component penetrates upto 3.2 m and 0.25 per cent sky component upto 7.3 m.(8).

The spread of a given sky component can be defined as the lateral distance covered by a given sky component at half its penetration depth on the work plane. The magnitude of the spread of sky component is obtainable from fig 10. In the above example the spreads for 2.7 m long and 1.5 m high window are 5.0 m and 9.8 m respectively (for 2% and 0 25% sky component) The penetration and spread of sky component depend upon the sill height of the window above the work plane Fig (7) and (8) hold good when the work plane is coincident with the sill level For higher sill levels a correction can be applied from fig 11. If the window sill is below the work plane, the effective height of the window contributing to the sky component will be that above the work plane The entire window, however, contributes to the reflected component.

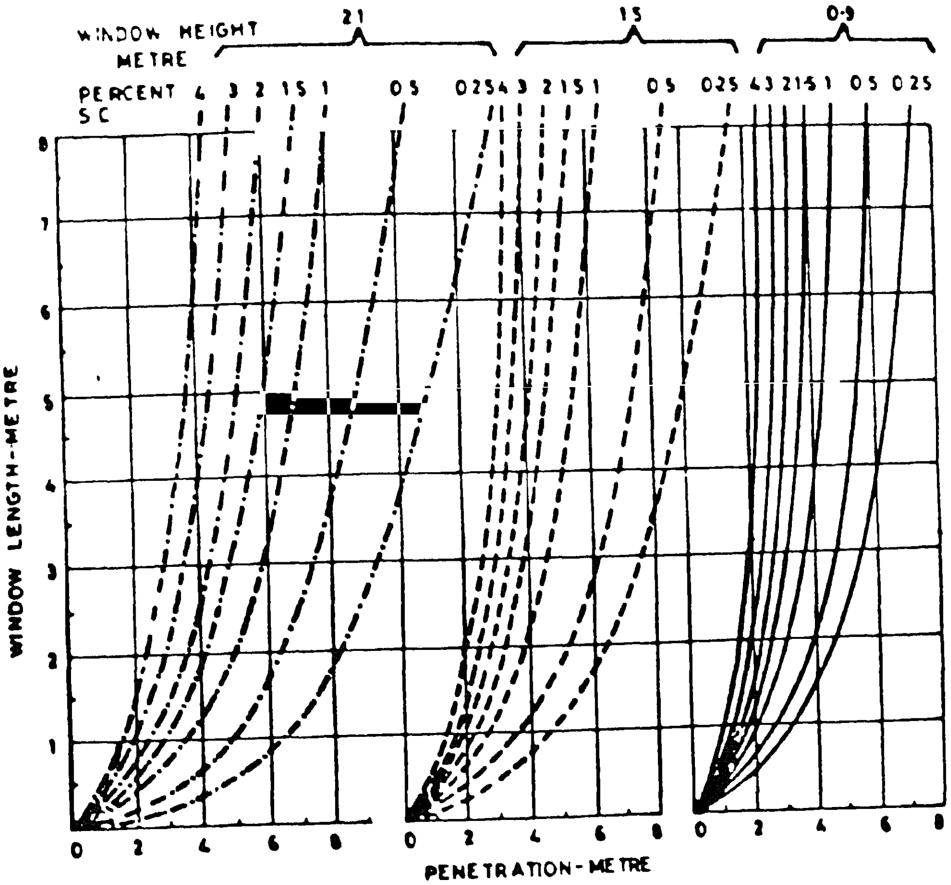


FIG 9 PENETRATION OF SKY COMPONENT (PERCENT SC) FOR SILL COINCIDING WITH THE WORKING PLANE

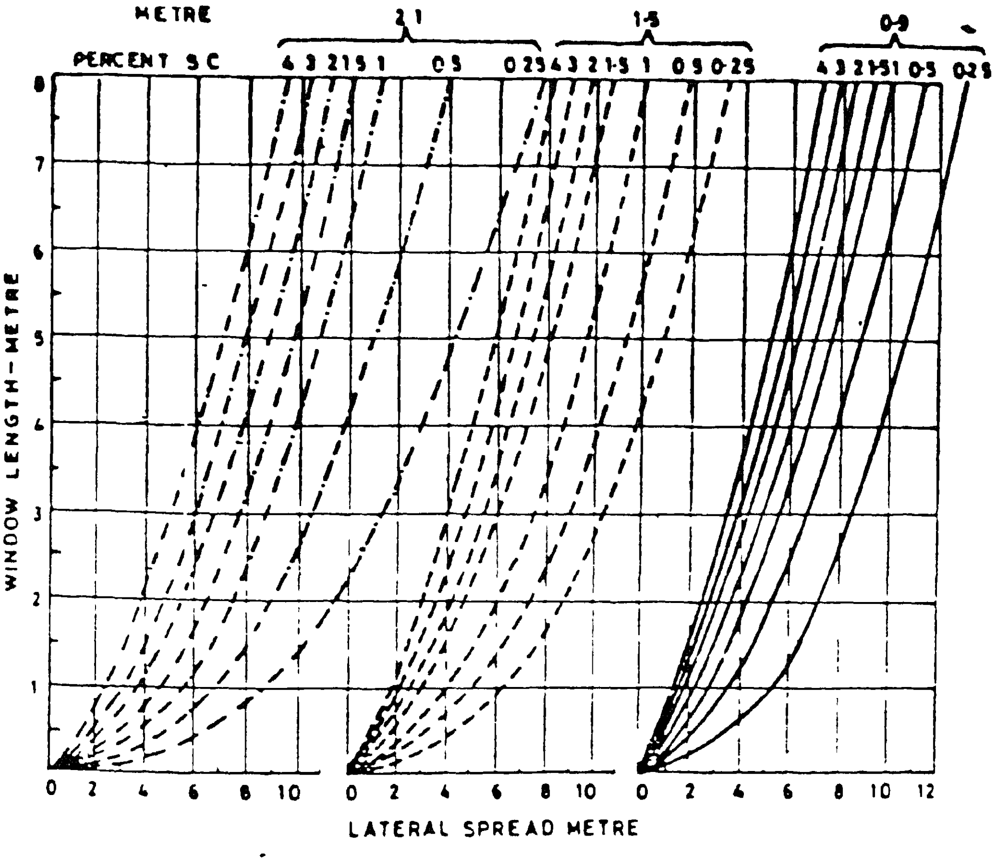


FIG 10 LATERAL SPREAD OF SKY COMPONENT (PERCENT S C.) AT HALF THE PENETRATION DISTANCE FROM THE WINDOW FOR SILL COINCIDING WITH THE WORKING PLANE.

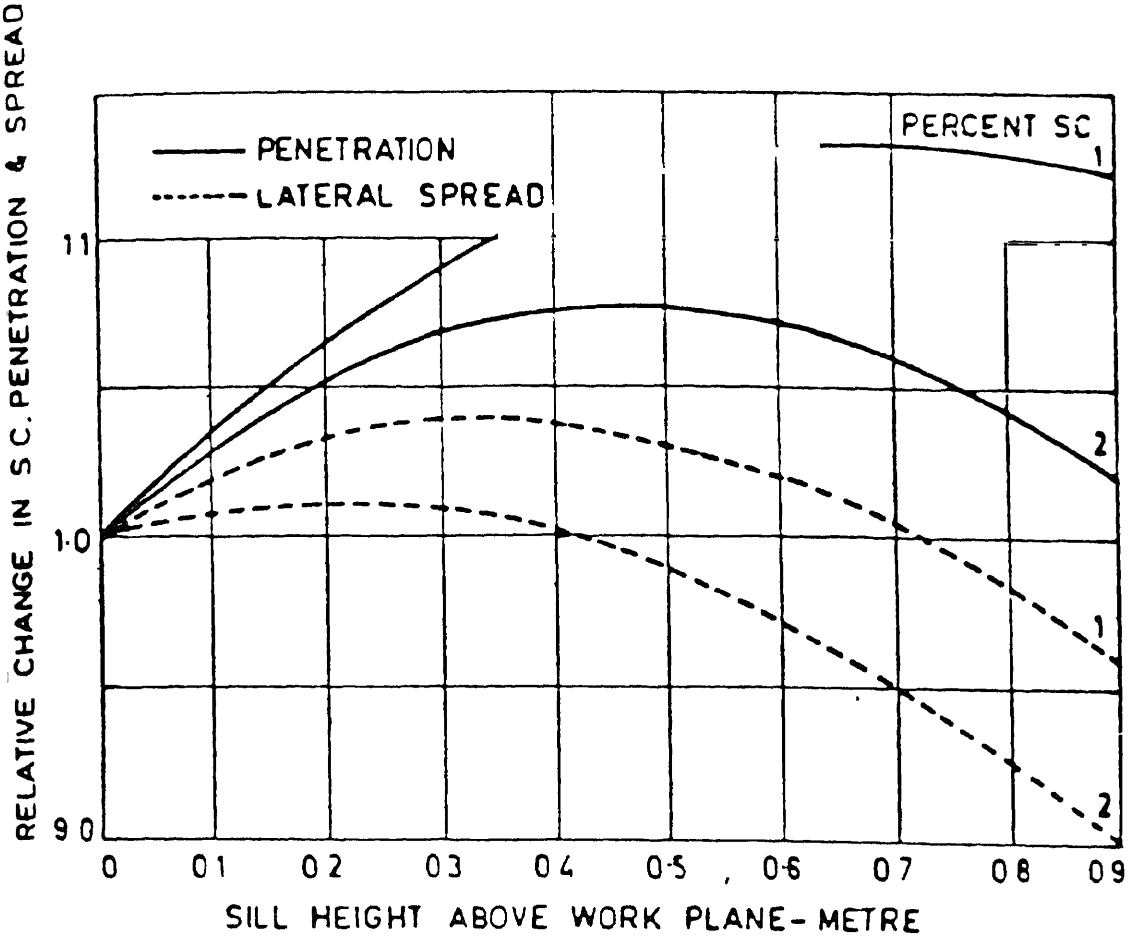


FIG 11 VARIATION OF THE PENETRATION AND SPREAD OF SKY COMPONENT (PERCENT S.C.) WITH SILL HEIGHT ABOVE THE WORKING PLANE.

VI. THE FIELD STUDY

As the definition, importance, theory and the design principles are read from the earlier chapters, one may be interested to know about the actual field situation. This ofcourse was the primary aim of the study.

Two major cities of the country were selected for the study, Delhi and Bangalore. The selection of Bangalore has special significance Bangalore is biggest city in the country lying in the moderate climatic zone where the scope of day lighting is maximum. In any part of the year Bangalore is under any kind of climatic stress This makes the designer free to use larger openings which improves the quantity of day light inside.

In Delhi the situation is different. It is subjected to severe climatic stress during different parts of the year. The design criteria for offices and residences also could be different. In offices there is good scope of using daylighting from almost mid September to mid April. But in houses bigger openings may result in excess of heat loss during nights. So, often it is a challenge for the designer to work out good designs

SURVEY CONDUCTED IN DELHI

Residential Buildings The survey was carried out in 200 households, including 2 roomed and 3 roomed DDA flats and SFS flats spread out all over Delhi. The selected sample has been listed in table 3.

The illumination levels are measured in two rooms of each house, the drawing room and one of the bed rooms. The lux level is measured with and without

internal shading devices like curtains, venetian blinds etc.(if any). The window positions and dimensions are noted. Simultaneous measurements were done on external illumination levels also. While measuring the external illumination level a shadow band was used to avoid direct sunlight. A few sample data sheets are shown in appendix-1.

Table 3: Apartments selected for study in Delhi

Sl.No.	Locality	LIG	MIG	SFS	Total
01	Ashok Vihar	4	4	2	10
02	Dilshad Garden	5	5	-	10
03	East of Kailash	5	5	-	10
04	Janakpuri	4	4	2	10
05	Kalkaji	4	-	6	10
06	Nand Nagari	5	5	-	10
07	Pitam Pura	5	4	1	10
08	Rohini	4	6	-	10
09	Saket	-	3	7	10
10	Shalimar Bagh	3	5	2	10
11	Vikas Puri	4	5	1	10
12	Mayur Vihar	2	6	2	10
13	Munirka	2	5	3	10
14	Tagore Garden	6	4	-	10
15	Mukherji Nagar	5	4	1	10
16	Madanpur Khadar	2	-	8	10
17	Kishan Garh	-	-	10	10
18	Lawrance Road	7	3	-	10
19	Paschim Puri	4	4	2	10
20	Sheikh Sarai	4	3	3	10
	Total	75	75	50	200

The study was conducted in the month of November and on fairly clear days. During most of the measurement periods the out side illumination level was 12,000 to 14,000 lux (excluding direct sunlight). Out of the '200' houses studied '48' of them were found to have excellent level of illumination DF (at the centre) more than 1.5% while '32' were having illumination level between 1 and

1.5%. Another '30' were also under satisfactory level of illumination (DF between 0.5 and 1%) and '90' of them were under poor daylight conditions (DF less than 0.5%). See table.4. It was also interesting to see that the window area provided in most of these houses were sufficient to provide a day light factor of above 1.5 at the centre of the room. But the actual levels observed were much below this.

Table 4: Number of households and their daylight factors in Delhi

Category No	DF%	Rating	No. of houses under each category	Percent-age
1.	Less than 0.50%	Bad	90	45
2.	Between 0.5 to 1.0%	Satisfactory	30	15
3.	Between 1 to 1.5%	Good	32	16
4.	Above 1.5%	Excellent	48	24

The major reasons for this are:

1) External obstructions in front of the window

2) Permanent posters are pasted in many of the window glasses and this makes the effective area too low to provide sufficient daylight.

It was also observed that the design has been made based on a gross assumption of window area/floor area ratio. No clear distinction has been made between windows located on longer and shorter walls and again between centrally located and located at corners. It was found that similar houses/rooms had completely different configurations of windows resulting in large differences in daylight factors. In some locations, there were constraints such as internal cabinets, doors etc. But in

general, it was noticed that there were constraints that could have been considered in the planning stage thus resulting in better daylight factors. Hence, it is seen that the location of the window is often not considered as an important design criteria. It may be noted at this stage that in CBRI method the location of the window is an extremely important design parameter.

Though CBRI has suggested multiplication factors for the window area whenever the height/separation ratio (ratio of the height of external obstruction above sill level to the distance of the obstruction from the window) exceeds 3, external obstruction was never found to be a design criteria in the actual field. Improved DF and household electricity consumption: The clear design sky defined for the daylight design is based on a solar altitude of 15o. Though this design sky takes care of the normal working hours in offices, one may doubt whether the same sky conditions may be assumed for the daylighting design in households The hours when daylighting is required in houses (which is in the evening hours) generally do not fall under the clear design sky period

Based on the altitude of the sun (for New Delhi) during the evening hours of a summer and a winter month, the outside illumination is estimated from fig. 12 The corresponding internal illumination (at the centre of a living room of a house) is worked out for different daylight factors from 0 50 to 2%. Fig. 13 and 14 show the variation in internal illumination for different DF percentages. Assuming that the need of switching the light occurs when the illumination level goes below 60 lux, it may be seen from fig. 13 and 14 that switch-on-time of lights may shifted by 30 about minutes by improving the DF percentage from 1 to 1.5 and again by further 10 minutes by improving DF to 2 percent. The total saving of electricity is

worked out in table 5.

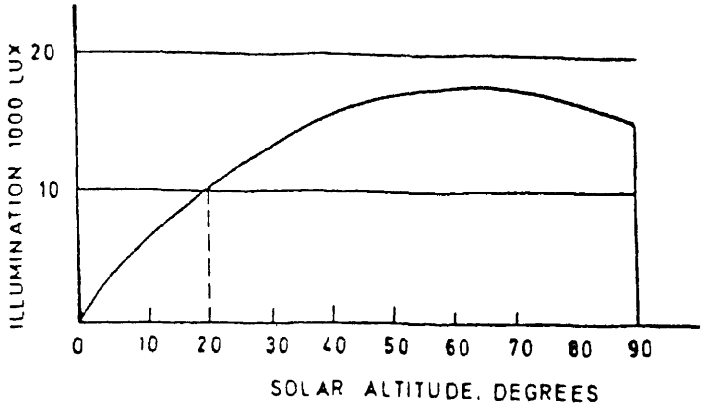


Fig.12 External horizontal illumination due to clear sky excluding direct sunlight.

It may be noted that a daylight factor of only 0.625% is recommended for living room as per IS 2440. This estimate is likely to be low for the sky condition existing during early

Table 5: Potential reduction in electricity consumption for changes in daylight factors

Month	Light swith on time for DF 1%	Light swith on time for DF 1.5%	Light swith on time for DF 2%	By improving DF% from 1 to 2 Total electricity saving/month			
				(1) For Incandesent		(2)For Fluoresent	
				Wattage	Saving(W h)	Wattage	Saving(W h)
December	16.70 hr (16hr 42 mts)	17.20 hr (17hr. 12mts)	17.40 hr (17hr 24mts)	100	100*42/60*30 2100	40+10 =50	50*42/60*30 1,050
June	18.35 hr (18hr.35mts)	18.60 hr. (18hr 36mts)	18 72 hr (18hr 45mts)	100	100*25/60*30 1,250	50	50*25/60*30 625

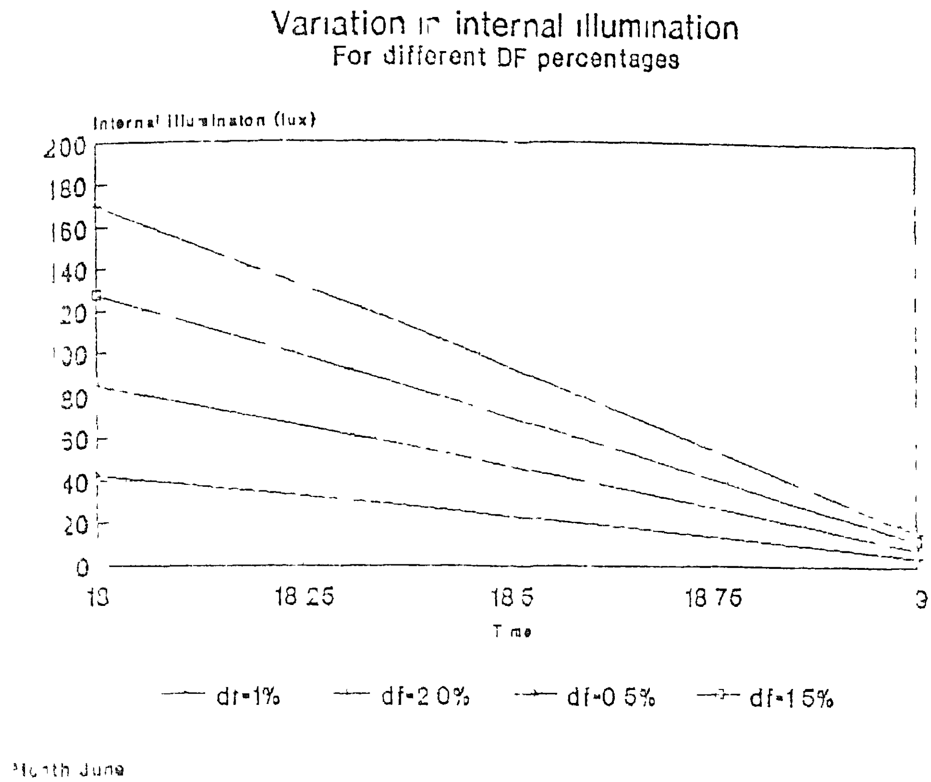


Fig.13 Variation in internal illumination for different DF percentages - For a typical summer month.

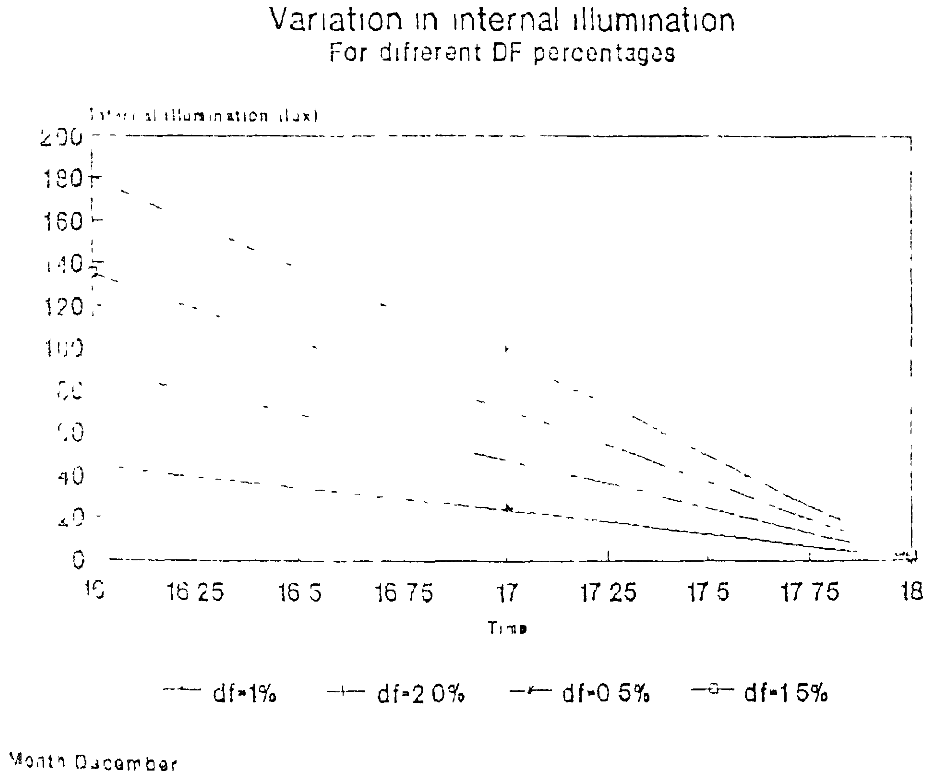


Fig. 14 Variation in internal illumination for different DF percentages - For a typical winter month.

morning and late evening. Hence, it may be worth while to review either the design sky condition for household daylighting design or improve the proposed design daylight factors for households thus ensuring better utilization of daylight in residential sector.

Looking into the survey data it can be seen that there is a possibility of improving daylight conditions for category 1 and 2 (60% of households come under this category).

If daylight factor is improved in two rooms of each household to promote them to the next category, the total saving of electricity per month for every 100 houses would be as given in table 6

Table 6: Potential reductions possible in electricity consumption by improving daylight factors

No. of houses for which the improvement of DF is effected	Shifting of light on time	Monthly saving of electricity if incandescent lamps are used	Monthly saving of electricity if flurocent lamps are used
45	30 mts	45*30/60*100*30 = 67.50 KwH	45*30/60*50*30 = 33.75 KwH
15	30 mts	15*30/60*100*30 = 22.50 KwH	15*30/60*50*30 = 11.25

Total saving per every 100 houses - 90 KwH 45 KwH

These values would be higher if the savings during the morning hours is also included.

Office Buildings: The field survey has been extended to office buildings also. Ten offices were selected from different parts of Delhi. Offices under private

and public sector have been included in the sample. It has been observed that in many of these buildings, there is ample scope of utilizing natural light.

For example, in the main hall of the 7th floor of an office building located in Lodi Road, large area of glazing is provided on the north side, to provide good diffused daylight. But the curtains are generally kept closed and the complete illumination is provided by artificial means. About 48 numbers of tube-lights are used to illuminate the complete hall of about 200 sq.m. area.

Lighting intensity was measured at different points in the room with the curtains open and all lights off On the first row of tables (near the window) the light level was around 660 lux towards the centre of the room it was 125 lux and on the rear side 40 lux.

This indicates that it is possible to provide the entire general lighting in the hall by daylight only supplementary and task lighting need to be provided by artificial means. Only about 16 tube lights are sufficient to provide the required illumination inside the hall. This would result in a direct load reduction of 1600 watts, which means, for every day of of sastisfactory sky conditions, the office can save about 12.8 Kwh of electricity per day

Similarly in some other offices too (located in Scope complex & Connaught Place) there exist scope for using natural light at least on tables and cabins located near the windows, but no real effort has been made in this direction.

In another office located in the International Trade Tower, Nehru Place, it was observed that very high illumination levels have been maintained almost entirely by artificial lighting. At every location the lighting level was found exceeding 500 lux and in many places it was more than 600 or even 700 lux. It

may be noted that as per Indian Standards only 150 lux (general) to 300 lux (desk work) is required for office buildings. The lighting can be cut down even by 50% without practically sacrificing any degree of visual comfort. Reduction in lighting also contributes substantially to the reduction of cooling load. Again in many of the cabins in the office it was seen that it is possible to get a lighting level of 150 to 200 lux by daylighting alone.

In another office in Scope Complex, the general lighting level was found very low The lighting level used for the desk work was less than 100 lux in most of the cases. The main reasons for this are:

- The artificial lighting provided was more of decorative in nature. The diffusers used are not the ones suitable for office buildings.
- The tinted glasses cut most of the natural light coming in making the daylight contribution extremely less.

In another office in Jan Path, very little artificial lighting was used. The lighting level (mainly daylight) was found satisfactory to a depth of 4 to 5m from the sides. But towards the interior side the levels are very poor mainly due to the improper distribution of tube-lights.

SURVEY CONDUCTED IN BANGALORE

Residential buildings: Bangalore is a city where the prospects of providing natural lighting is extremely high. The field study results proves to be no different Survey was conducted in 200 houses (160 independent houses and 40 flat types). The selection of the sample was done in a random fashion. However very small and extremely large houses were exempted from the study.

In most of these houses the day time use of artificial lighting was very little. Another Important feature observed was the contribution of ventilators in improving daylight factors. In many of the old houses the ventilators were provided close to the ceiling very high on the walls. This has been found quite useful in improving the daylight level inside. This phenomena was observed in some of the newly built apartments also. In one of the houses, in a small bed room (9' X 9'), there were only two ventilators and no windows and still they daylight factor was above 1% at the centre of the room. Table(7) gives the details of the sample selected for the study

Table.7 Apartments selected for the study in Bangalore

Sl.no	Locality	No. of houses
01	Jayanagar	20
02	Basavanagudi	05
03	Visweswarapuram	10
04	Vijyanagar	10
05	RPC Layout	10
06	Rajaji Nagar	20
07	Malleswaram	10
08	Yeswanthapur	10
09	Mathikere	20
10	AGS Layout	05
11	MSR Nagar	10
12	Gokula	05
13	Sadashivanagar	05
14	Vasanthanagar	05
15	Indira Nagar	20
16	Jeevan Bima Nagar	10
17	C.V.Raman Nagar	10
18	Vinayakanagar	10
19	Builders Apartments	05
	TOTAL	200

Office buildings. The survey has been extended to Office buildings also. Survey has been done in 20 offices selected at random. The lighting measurements were taken

in main halls and in a few cabins. In most of these offices almost entire general illumination was done by natural means. The actual glass area provided was found much more than what is actually required. Since the climatic conditions permit this might not be creating any discomfort so that excessive use of curtains or smoked & tinted glass were not necessary unlike the offices in Delhi. However the quality of lighting can't be considered very good as the design of shading devices were not carried our properly and as a result lot of direct sunlight also was found peeping in. This gives rise to some amount of glare problem. In any case almost 75% of the artificial lighting were off in the most of the visited offices during working hours.

Table.8 gives an idea of the daylight utilization in Bangalore.

Table.8 No. of households and their daylight factors in Bangalore.

Category	DF %	Rating	No. of houses	%
1	Less than 0.50%	Bad	38	19
2	0.5 to 1 %	Satisfactory	16	08
3	1 to 1.5 %	Good	60	30
4	above1.5 %	excellent	86	43

Sample data sheets are attached in appendix-1

Though in comparison with Delhi the daylight utilization in Bangalore was found much better it does not mean that the design principles laid down by CBRI has been followed in Bangalore. Infact for many houses the window area provided was much more than what is required. It is the flexibility provided by the climate that plays the major role.

Inferences from the field study are further discussed under section-X, Conclusions and suggestions.

VII. THE COMPUTER AIDED METHOD OF DESIGN

The literature review and the field studies brought out the following facts:

1. Guidelines are prepared by CBRI and the Bureau of Indian Standards for the design of fenestration for daylighting.
2. It has been observed that these guidelines are not effectively used in the actual field
3. It may be useful to develop simpler methods based on same principle.

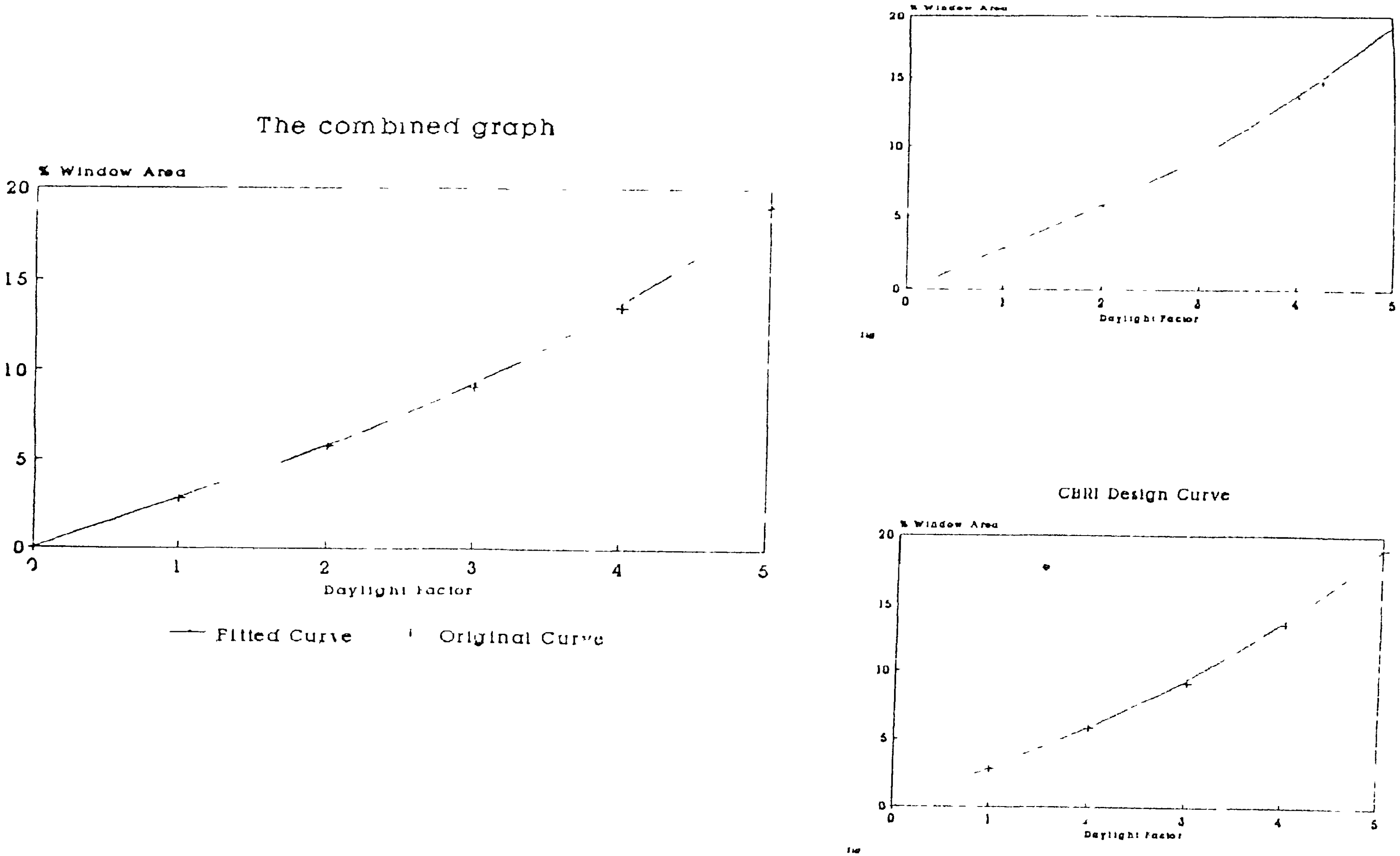
With this in mind a computer aided method has been developed based on same principle of design. The assumptions used in the design method proposed in IS 2440 has been retained.

Polynomial equations have been fitted for the 16 design curves considering percentage window area and DF based on metallic sashes as two axes. For other cases, wooden sashes and the effective area option, the DF has been modified by suitable multiplying factors

A sample equation is given below.

$$x = -0.00873 + 2.851058 * Y - 0.11289 * Y^2 + 0.060648 * Y^3 \qquad [7]$$

where 'x' is the % of window area to floor area and Y is the daylight factor.


The combined graph

CBRI Design Curve

Fig.15 CBRI design curve and the fitted curve

The design curve proposed by CBRI and the curve given by the above equation are shown in fig. 15.

Another multiplication factor has been introduced to take care of the external obstruction in front of the window.

The program has been developed in interactive mode. A simplified flow diagram is given in fig. 16. The user can just select his options and arrive at the required window area. Since standard window heights of 0.90 m 1.50 m and 2.1 m are used generally, and can be chosen depending on the spread and penetration required, the other dimension (width) can be easily found out.

The method exactly follows the design curves suggested in IS-2440. It is highly user friendly and will be extremely useful for the architects and building technologists to bring out good designs. In addition to the window area the program also gives the number of supplementary lighting (cool daylight fluorescent tubes) to be used in the daytime (The curves given in fig 17 is used (8) to compute the supplementary lighting requirement) and the number of lights required if the complete illumination is done artificially This information will be extremely useful for lighting design (integrated) of office buildings
The design procedure is illustrated through a design example in Appendix-II.

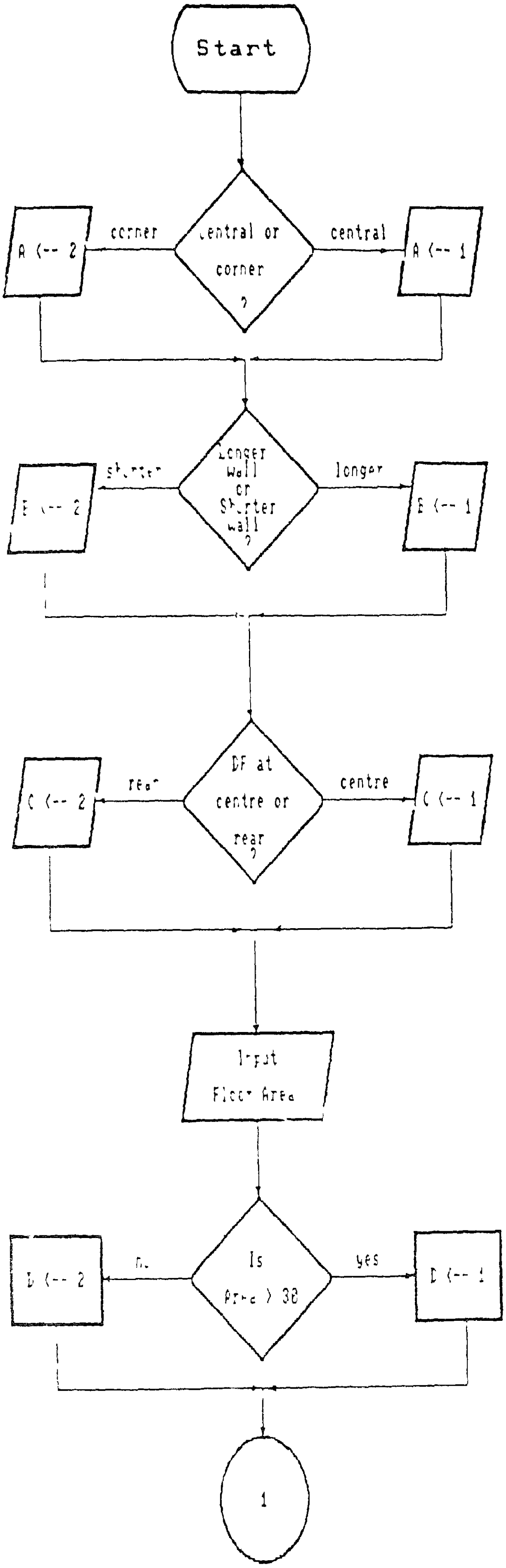
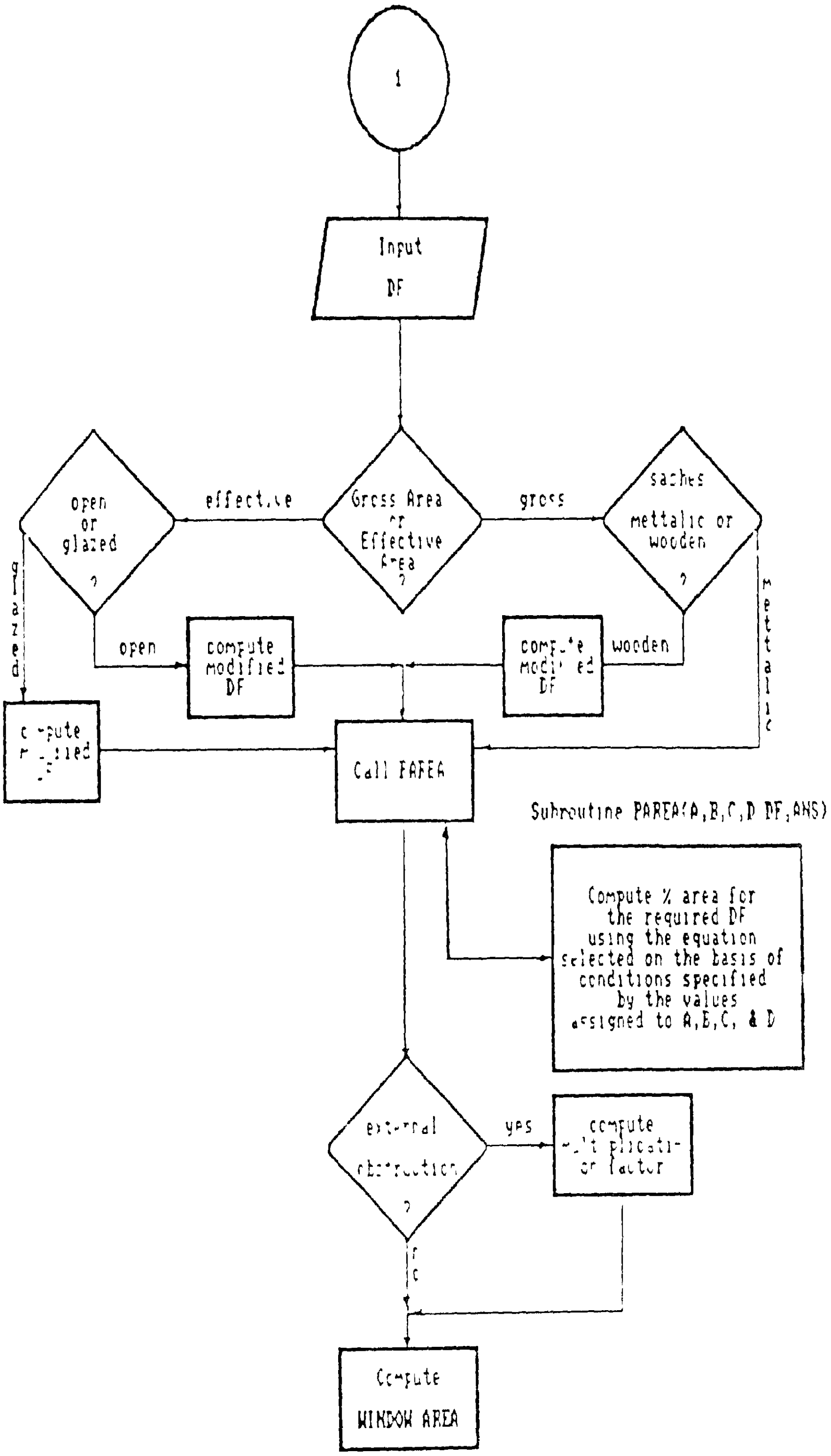


Fig.16 Flow chart of the computer program


1
Input
DF
open
or
glazed
?
effective
Gross Area
or
Effective
Area
?
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sashes
mettalic or
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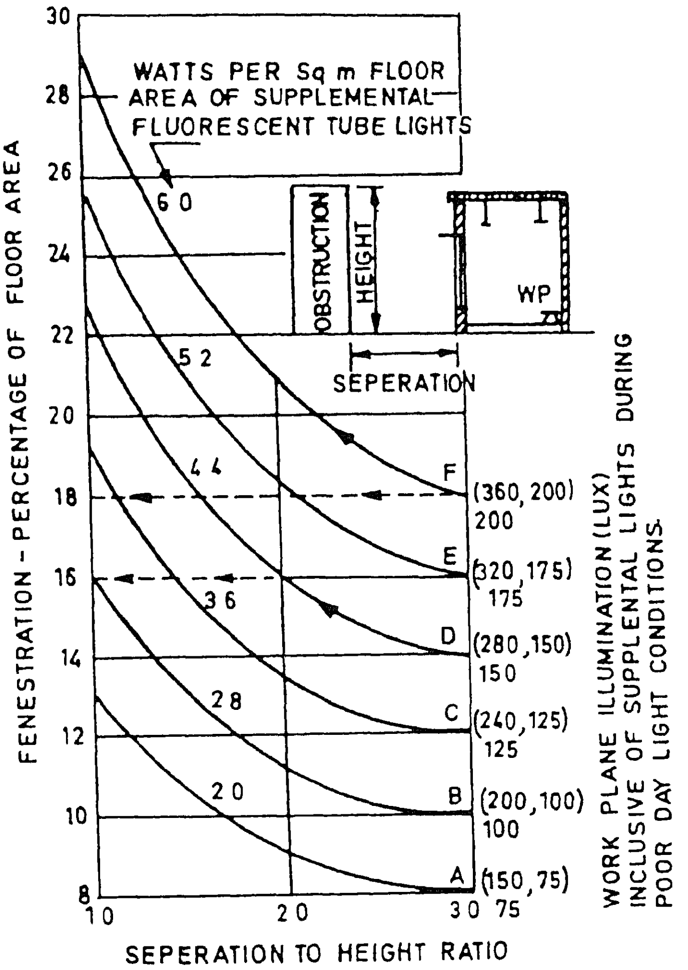
?
glazed
open
compute
modified
DF
compute
modified
DF
wooden
mettalic
compute
modified
DF
Call PAREA
Subroutine PAREA(A,B,C,D DF,ANS)
Compute % area for
the required DF
using the equation
selected on the basis of
conditions specified
by the values
assigned to A,B,C, & D
external
obstruction
?
yes
compute
multiplication
factor
no
Compute
WINDOW AREA



3.17 Nomograph for daylighting and supplemented lighting d
of buildings.

VIII. HEAT GAIN THROUGH FENESTRATION

The fenestration generally provided for daylighting, leads to additional heat gain. ASHRAE's shading coefficient method is generally used to estimate heat gain through fenestration. The method is briefly discussed below.

The total instantaneous rate of heat gain through the glazing material may be expressed by the block equation

Total heat admission = Radiation transmited through glass + Inward flow of solar radiation absorbed by glass + Heat flow due to outside inside temp.diff. [8]

Since the first two terms of the above equation are related to the incident solar radiation, while the third term occurs whether or not the sun is shining Combining the first two the equation can be rewritten as

$$\textit{Total heat admission through glass} = \textit{Solarheat gain} + \textit{conduction heat} \qquad [9]$$

or

$$q_A = FI_t + U(t_o - t_i) \qquad [10]$$

where F is a dimensionless ratio of solar heat gain to the incident solar radiation. This solar heat gain coefficient F is a characteristics of each type of fenestration and varies with incident angle.

Because of constantly growing number of types of fenestration, and the infinite variety of combinations of incident angle it is impractical to attempt to give all-inclusive directions for estimating as per the above equation under all

possible conditions. Instead, a procedure (shading coefficient method) has been developed by ASHRAE for the estimation of solar and total heat gain through fenestrations.

Shading coefficient method: A reference glazing material has been considered. ASHRAE has selected double strength sheet glass with 0.86 transmittance, 0.08 reflectance and 0.06 absorbance at normal incidence for this purpose (14).

The shading coefficient (SC) is defined as the ratio of the solar heat gain through a glazing system under a specific set of condition to the solar heat gain through a double strength sheet glass under same set of conditions.(14) This ratio is a unique characteristic of each type of fenestration and is represented by the equation.

$$SC = \frac{Solar\ heat\ gain\ of\ Fenestration}{Solar\ heat\ gain\ of\ double\ strength\ glass}$$

For the purpose of ASHRAE calculation procedure, the heat gain through sunlit double strength glass are designated as the solar heat gain factors (SHGF) A procedure is given for the computerized calculation of solar heat gain factors. Knowing Solar heat gain factor, for any glazing material or fenestration other than double strength sheet glass the solar heat gain will be

$$\text{solar heat gain} = \text{Shading coefficient of the fenestration} * \text{SHGF for a given orientation and existing conditions} \qquad [11]$$

Total instantaneous heat gain will be:

$$qA = (SC)(SHGF) + U(t_o - t_i) \qquad [12]$$

The Procedure for calculation of SHGF: The first step is the estimation of direct and diffused radiation on surfaces of different orientations. The next step is the determination of the following quantities.

$$\sum_{j=0}^{5} a_j cos j\theta \qquad [13a]$$

$$\sum_{j=0}^{5} t_j cos j\theta \qquad [13b]$$

$$\sum_{j=0}^{5} \frac{a_j}{j+2} \qquad [13c]$$

$$\sum_{j=0}^{5} \frac{t_j}{j+2} \qquad [13d]$$

For the calculation of these quantities values of a_j and t_j for j=0,5; given in data form in ref.14. Solar heat gain transmitted component is given by the equation

Transmitted component=

$$I_D \sum_{j=0}^{5} t_j cos j\theta + I_d * 2\sum_{j=0}^{5} \frac{t_j}{j+2} \qquad [14a]$$

Absorbed component is given by the equation

Absorbed component=

$$I_D \sum_{j=0}^{5} a_j cos j\theta + I_d * 2 \sum_{j=0}^{5} \frac{a_j}{j+2} \qquad [14b]$$

where I_D and I_d are the direct and diffused solar radiation on the fenestration

$$Solar\ Heat\ Gain\ Factor\ (SHGF) = Transmitted\ +\ Ni\ *\ Absorbed \qquad [15]$$

where Ni is the inward flow fraction of the absorbed component.

For still air (natural convection condition) at the inner surface of the fenestration and a 7.5 mph at the outer surface $N_i (N_i = h_i/(h_i + h_o))$ will be equal to 0.267. (14). Shading coefficients usually supplied are based on this value. [h_i and h_o are the coefficients of inside and outside surface conductance.]

IX. DAYLIGHTING & ELECTRICITY CONSUMPTION

As mentioned earlier, one of the major reasons for not using daylight is the possible increase in heat gain, and the resultant increase in electricity consumption for space conditioning. An attempt is made in this section to look into the actual heat gain phenomenon through glazing vs. reduction in electricity consumed for lighting.

In non air-conditioned and naturally ventilated building (generally in temperate zones), a good daylighting design can effect substantial amount of savings. On getting around 160 lux of general illumination 10% fenestration area supplemented by about 3.6 W/sq.m. of artificial lighting (8) will be sufficient, where as to achieve the same illumination level 10 to 12W/sq.m. of artificial lighting (cool daylight fluorescent tubes) is required. So, for every sq.m. area there is a direct saving of 8-10 watts of energy.

But for air-conditioned buildings the situation is slightly different. There, the increase in window area will directly contribute to the increase in air-conditioning load. Some calculations have been done to compare the effect of natural lighting and artificial lighting on the cooling load and total electricity consumption. The following assumptions are made.

1 Day lighting design is done using CBRI design charts.

2. 33.33% increase in window size is assumed to take care of external obstruction.

3. Lumen method of design is done for artificial lighting design.

4. Cool-daylight fluorescent lights are used for artificial lighting.

5. The loss at the ballast is 10W/Light

6. The room area lies between 30 and 60 sq.m.

7. Design illumination level is 160 lux (corresponding to 2 DF on standard sky condition)

8. Day-lighting design is done for 2 DF at the centre of the room.

9. The window is assumed to be shaded completely from direct sun.

Step 1 : Window area: Assume the floor to be 'A' sq.m. From the CBRI charts (8) for the above conditions, the window area (effective), with 3mm glazing can be obtained as around 10% (Including 33.33% increase).

i.e. 10 * A / 100 sq. m. = 0.10 A Sq.m.

Step 2 : No. of lights: Using lumen method (7) the number of lamps can be calculated as

$$N = \frac{E * A}{\phi \mu d} \qquad [16]$$

where

E = illumination level (lux)

A = Area of the room

ϕ = luminous flux of the lamp

μ = utilization factor

d = maintenance factor

Assuming a utilization factor of 0.45 and maintenance factor of 0.70 (ref.7). The number of lamps works out to be:

$$N = \frac{160 * A}{2440 * 0.45 * 0.70} = 0.20 * A$$

Step 3 : Heat gain through the window (Hw): Assuming the diffused solar radiation on vertical surface to be 'W' w/sq.m and heat transmission through glass to be 80 percent.

Radiation heat gain $= 0.8W * 0.10A = 0.08$ WA watts

Conduction heat gain $= Ug * 0.10A*$ temperature difference (say $t_d =$ $5.23 * 0.10A * t_d = 0.523At_d$ watts

$H_w =$ total heat gain $= (0.08W + 0.523t_d)A$ watts

Step 4 : Heat gain due to artificial lighting· Heat gain due to artificial lighting (HL) is given by:

$H_L = 50 * 0.20 = 10 * A$

Additional heat gain from wall ($U_w = 1.5w/m^{2o}C$, say)

$= 1.5 * 0.10A * t_d = 0.15t_d$

Total heat gain $(H_L + H_{wall}) = 10A + 0.15t_d$

Step 5 : Comparison of electricity consumption in two cases: Total consumption of electricity energy can be compared by assuming that 'R' units electricity energy is consumed to take care of 1 unit of air-conditioning load.

a) Total consumed in 1 hr. when the natural lighting is used.

$$E_N = R * A * (0.08W + 0.523t_d) watt - hour \qquad [17a]$$

b) Total energy consumed in 1 hr. when artificial lighting is used

$$E_A = (10 + 0.15t_d)R * A + 10A \qquad [17b]$$

Equating the two we can arrive at an equation for the limiting value of td as:

$$t_d = \frac{R * (100 - 0.80W) + 100}{3.73 * R} \qquad [18]$$

As t_d represents the difference in temperature between inside and outside, above equation can guide to decide whether to go or not for natural lighting.

Since the value of 'W'seldom exceeds 300W/Sq.m (ref.15 data), and the value of 'R' can go below 0.50 for efficient air- conditioning systems, it can be seen from equation (18) that, for most of the places it is feasible to go for natural lighting. As the value of 'W' has high influence on the value of td (see sample calculation), it is very important that the fenestration has to be properly shaded from direct sunlight. Also the windows should be located properly to get the required spread and penetration of natural light inside the room

The equation leads to the following conclusions:

1. The t_d value computed using the developed equation can be used as a useful guide to decide upon the feasibility of natural lighting in air-conditioned buildings.

2. For most of the places, during most of the times, the difference between the outside and inside temperature does not exceed td and therefor natural lighting can certainly save substantial amount of energy apart from providing a pleasing working environment.

Sample calculation Assuming that 2 Kwh of electricity is consumed to remove a cooling load of 1 ton :

$$R = 2/3.48 = 0.58$$

From equation. 18 :

For W= 300 W/Sq.m the value of td works out to be 9°C and for W= 250 W/Sq.m the value of td will be equal to 19°C From the data for difused radiation given in ref.15 it can be seen that the value of W (Diffused radiation on a vertical surface) seldom exceeds 300 W/Sq.m

X. CONCLUSIONS AND SUGGESTIONS

Analysis based on the literature survey and the field study leads to certain definite conclusions

(I) GENERAL

(i) Power shortages are likely to continue at least through the Eighth Five Year Plan. Hence there is a need to identify all possible options that would assist in reducing the gap between demand and supply. Daylighting is one such option.

(ii) The total requirement of lighting is met by a combination of natural lighting and artificial lighting, the mix depends on the availability of natural light. Increased use of daylight or natural light will result in reduced consumption of electricity due to reduction in artificial lighting.

(iii) While increased use of daylight by the domestic sector would lead to a reduction in the peak demand, which occurs during the evening hours, daylighting leads to an overall reduction in energy consumed, in the commercial sector.

(iv) The so called urban architectural style doesn't give importance to daylighting. The concept of the openings/glass used is often limited to decorative purposes

(v) The power tariff must be playing an important role in making one opt for daylighting. In Bangalore were the domestic power tariff is much higher than that of Delhi, the people were found more worried about using artificial lighting during day time. And in some of the poorly daylit houses they were asking suggestions for improving daylighting, where as in Delhi the people were not found much bothered in this matter. Low energy pricing can lead to under-utilization of the natural light.

(II) DESIGN ASPECTS

(i) CBRI has developed very useful guidelines for the design of fenestration for daylighting. But unfortunately these methods are seldom followed in the actual field. A casual talk with a couple of architects in Delhi and Bangalore revealed that they know very little about design for daylighting and they never bother to follow the CBRI charts for fixing the size of the openings.

(ii) The CBRI method is based on design charts and the designer may find it difficult to apply for quick solutions. The software supplied with this report take care of this difficulty. This method is just a computerized version of the CBRI design charts.

(iii) Climatically India can be broadly divided into six regions The scope of daylighting vary from region to region. The survey results from two different regions assured that a single standard is not adequate for the whole country. However this problem could be tackled by suggesting the daylight factor requirement for different functional areas in each of the climatic zones.

(iv) It is also suggested that there can be two daylight factors recommended for a single functional space. One could be based on the minimum requirement, which stands the same as the present one. And the second one should lead to providing a maximum fenestration area, but still could keep the space out of any kind of thermal discomfort or glare problem. This factor will vary from region to region, but will certainly ensure a complete utilization of the natural light. Concept of degree-days could be used to work out these factors. Developing this factor require quite involved research work and is beyond the scope of this report.

(v) It is also felt that the design sky condition established is valid only for office buildings. Adopting the same standards for the residences may

lead to under-utilization of daylight. This is mainly because, the main house hold activities take place in the early morning and late evenings hours when the sky conditions are generally poorer than the design sky condition. A daylight factor of 0.625, presently set for living rooms is inadequate to provide the required amount of illumination during the main functional hours.

(III) RESIDENTIAL BUILDINGS

(i) Though in the design of households surveyed, not much importance was given for daylighting, reflected from the location and sizes of windows in the households surveyed, the amount of daylight available inside was not that bad. However the quality of lighting was not satisfactory (Problems of direct sunlight coming in, glare problem, inadequate spread and penetration were observed). If daylighting is to play an important role in reducing electricity consumption both quality and quantity should be maintained, and for that a good deal of planning has to go into design of size and location of windows in households.

(ii) Small openings provided close to the ceiling is found very effective in improving the quantity of daylight inside. So it is suggested that about 25% of the fenestration area calculated as per the CBRI method shall be provided at a higher level close to the ceiling (This could be doubly glazed in places where winter is severe) Even on a west facing wall this could be tried

(iii) From table.6 it can be seen that an increased use of daylighting in households is likely to reduce the demand for electricity by about 45 to 90 kWh per month, for a group of 100 households and more importantly this would occur during the evening hours when the power system has its peak demand for the day.

(IV) OFFICE BUILDINGS

(i) In almost all Offices surveyed in Delhi and Bangalore it is found that the total glass area provided is 2 or 3 times more than what is actually required for good daylighting. This makes a lot of unwanted radiations to come in. More than increasing the temperature inside this results in increase of the surface temperature of the objects on which it is falling. This creates discomfort for the occupants. Also it produces glare problems. To take care of this, often the entire glass area is covered with thick curtains or coated with suncontrol films through out. Some times both are used. This makes the daylight availability insufficient.

(ii) A proper integration of natural and artificial lighting is not attempted in most of the offices surveyed. The lighting designers have almost completely ignored the natural light available inside. Also the principles and guidelines provided by CBRI & BIS are not followed. In one of the offices in Delhi where there was some interior being redone, it could be seen that the situation after the interior is redone would be very similar to the other offices where the entire illumination is by way of artificial lighting

(iii) In offices, all the lights provided are simply switched on without checking whether it is actually required or not.

(iv) The persons working in offices and other commercial establishments are slowly getting used to the artificial environment provided by the electric lights and are not recognizing the advantages of using natural lighting. Hence little effort is made to open the curtain (the internal shading device) to use daylight on an increasing scale.

(v) One of the reasons often given for not opting for daylighting is that, increased use of daylighting would result in increased consumption of electricity due to increased demand for space cooling. Calculations (sample

calculation in section IX) have shown that it does make more sense to use increased daylighting. It the fenestration area is designed as per standards, for most of the places and for most of the parts of the year it is daylighting that leads to reduction in electricity consumption. Increased use of glazing and increased use of daylighting are two differnt things.

(vi) A few suggestions are listed below which could help in improving the daylight situation in offices:

   (a) A fenestration area equivalent to 2-4% of the total floor area or 25% of the total fenestration area calculated base on the CBRI method shall be provided high on the walls (near the ceiling) and this could be of complete opening or could be of plane glass depending up on the situation. Also this should be evenly distributed over the walls.

   (b) As far as possible avoid the use of suncontrol films and smoked glasses; use plane glass or opening depending upon situations. If the excessive glass area is not provided and the glass area is properly shaded using well designed sunshades, it normally doesn't cause any discomfort.

   (c) The total amount of artificial light used in an office should not exceed 15W/Sq.m (connected load). And normally only 25% of this should be used during daytime (as supplementary lighting) and this should have separate a control. Heavy penalty should be imposed on offices having more W/sq.m of connected load for lighting. Also some incentives may be given to those of them having connected load for lighting less than 5 W/Sq.m.

As mentioned earlier, there is an increasing trend to use artificial lighting as against the use of daylighting. There is a need to carry out a programme to educate the population on the benefits of increased use of daylighting. In addition

to this, special efforts would need to be made to draw the attention of the building contractors, architects, and other professionals in this area to ensure that adequate attention is paid to this important subject which can contribute to reducing the gap between demand and supply of electricity. This is particularly, important in view of the fact that there would a large stock of new household and offices, where planning now would result in maximum use of daylighting.

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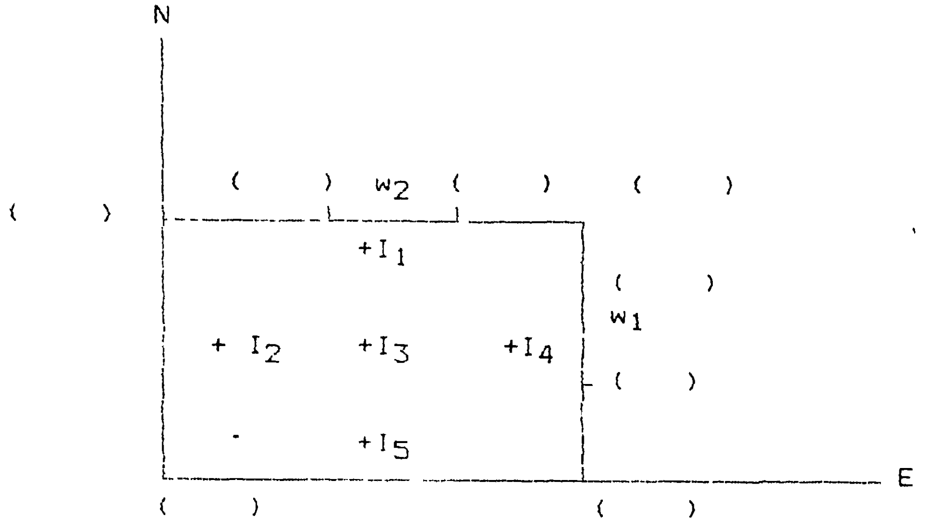
APPENDIX - 1

DELHI

Data Sheet

Give a neat plan diagram of the room in a separate sheet with co-ordinate axes as shown below and mark the co-ordinates.

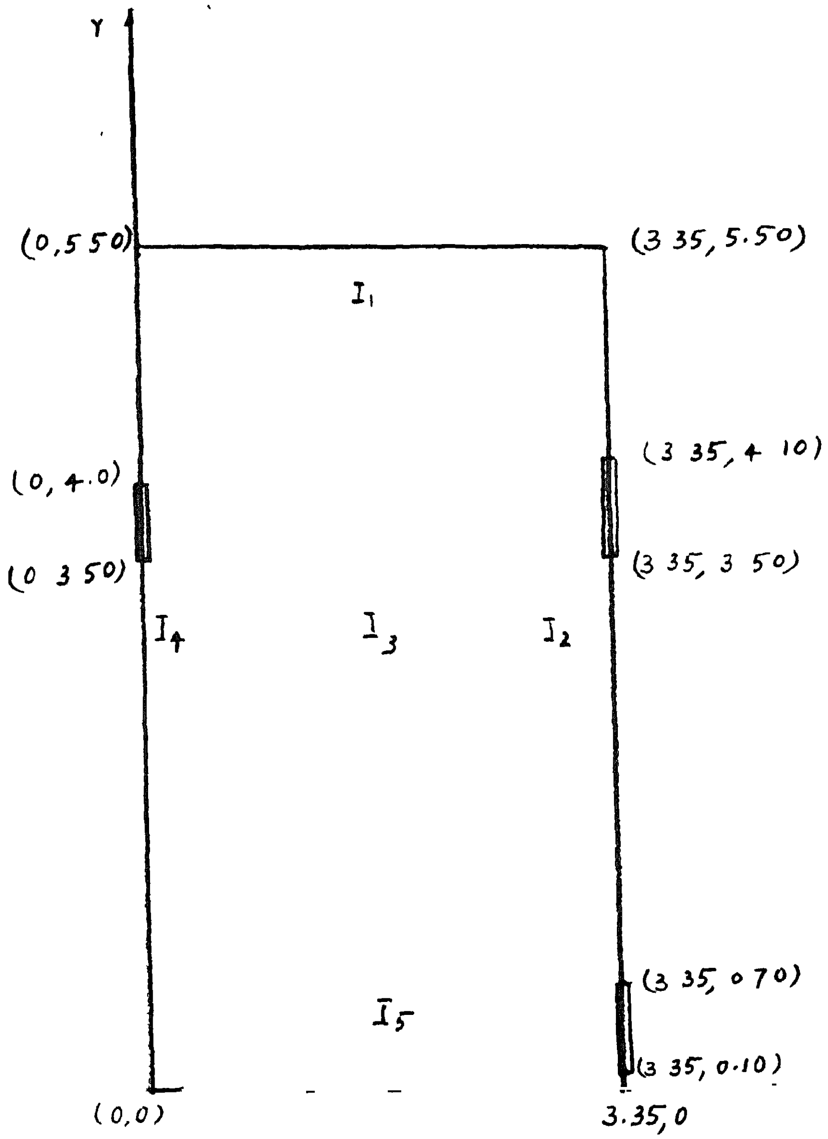


01.	Address with Floor no.	22 C, Ashok Vihar 1 IInd floor
02.	Type of the building	Residential
03.	Type of the room	Drawing room
04.	The day and time when the measurements are made	02-11-91, 1.25 p m
05.	No. of windows (Mark w_1, w_2 ------ in Fig.)	3
06.	Window Height	90 cm
07.	Type of external shading device	Horizontal & Vertical over hangs
08.	Type of internal shading device	curtain
09.	Window glazing type	plain
10.	Normal time when the lights are switched on	5.30 p.m
11.	Colour of internal finishing (Dark, Medium, Light)	Light

ILLUMINATION LEVEL IN LUX

Points	Co-ordinates	Light level with internal shading	Light level without internal shading	Remarks
I_1	(1 66, 5 25)	25	225	
I_2	(3.10 , 2 75)	30	300	
I_3	(1.66 , 2 75)	39	470	
I_4	(0 25, 2.75)	12	200	
I_5	(1.66, 0.25)	11	100	
O_1	-----		12,980	
O_2	-----		15,000	

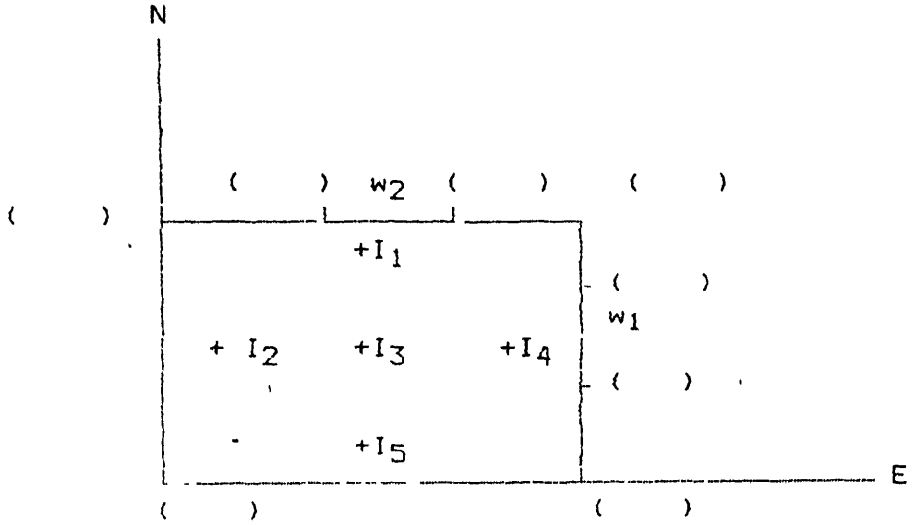
SPACE FOR THE FIGURE



DELHI

Data Sheet

Give a neat plan diagram of the room in a separate sheet with co-ordinate axes as shown below and mark the co-ordinates.

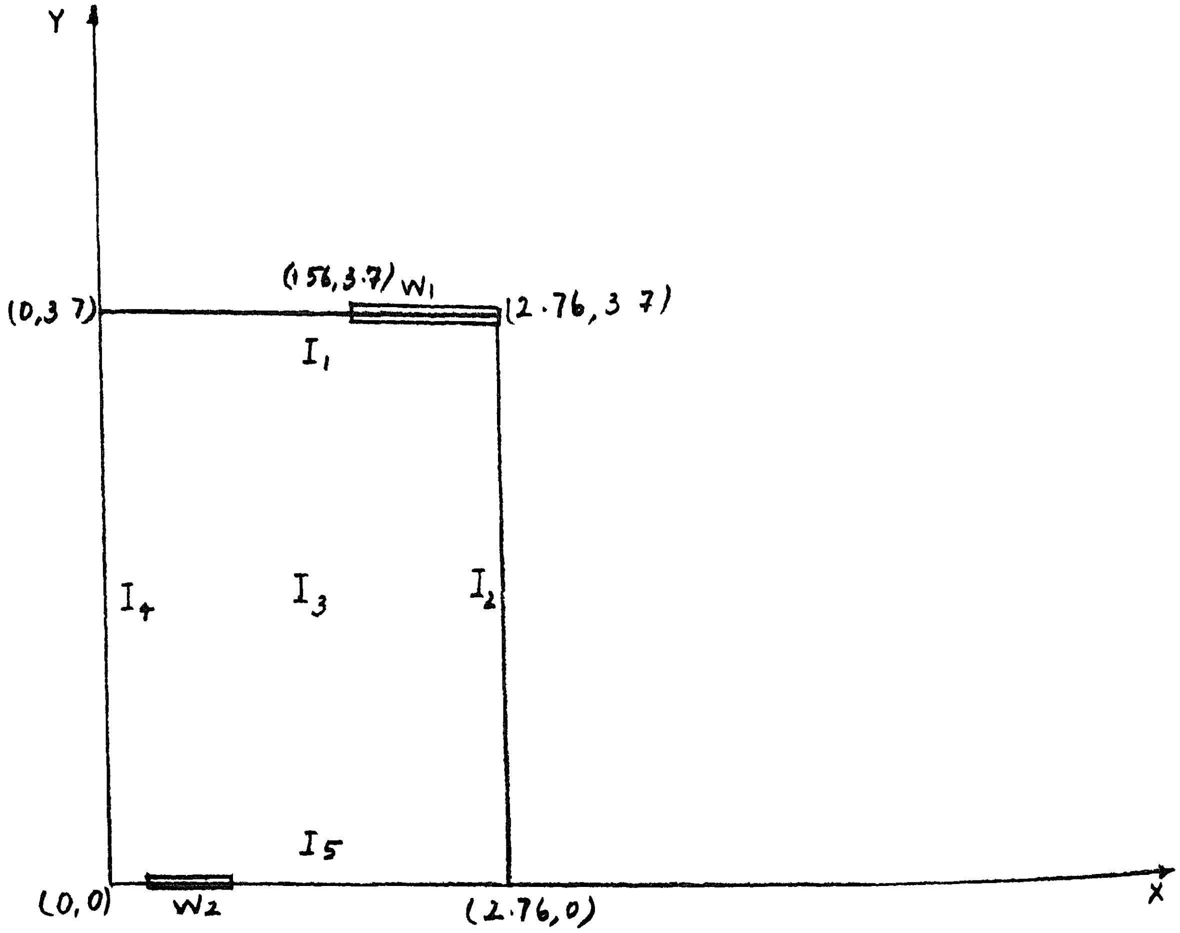


01. Address with Floor no.	56-M, Mayur Vihar IV IIIrd floor
02. Type of the building	Residential
03. Type of the room	BED room
04. The day and time when the measurements are made	13-11-90, 11.45 AM.
05. No. of windows (Mark w_1, w_2 ------ in Fig.)	2
06. Window Height	90 cm
07. Type of external shading device	Horizontal overhangs
08. Type of internal shading device	curtain
09. Window glazing type	plain
10. Normal time when the lights are switched on	5 30 pm.
11. Colour of internal finishing (Dark, Medium, Light)	Light

ILLUMINATION LEVEL IN LUX

Points	Co-ordinates	Light level with internal shading	Light level without internal shading	Remarks
I_1	(1.38, 3.45)	14	470	
I_2	(2.5, 1.85)	5	145	
I_3	(1.30, 1.85)	4	115	
I_4	(0.25, 1.85)	3	100	
I_5	(1.38, 0.25)	4	150	
O_1	———		14,350	
O_2	———		14,870	

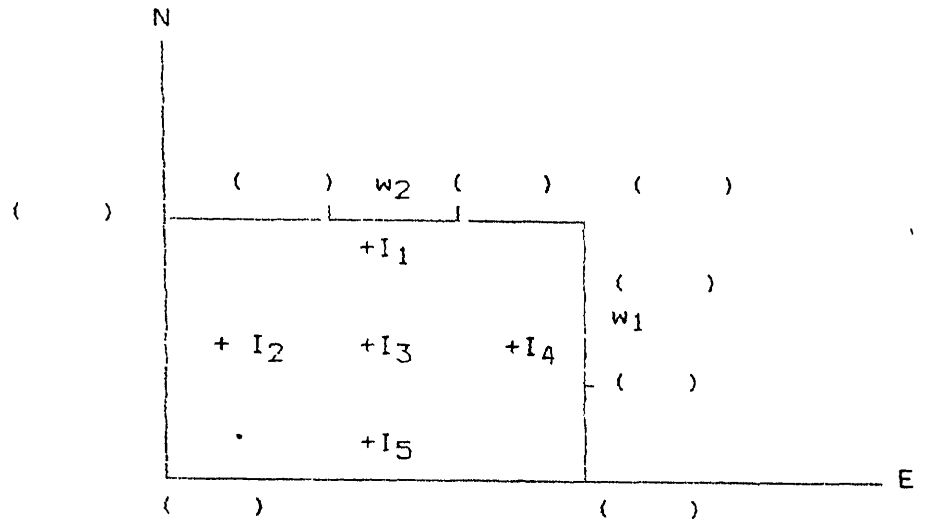
SPACE FOR THE FIGURE



DELHI

Data Sheet

Give a neat plan diagram of the room in a separate sheet with co-ordinate axes as shown below and mark the co-ordinates.

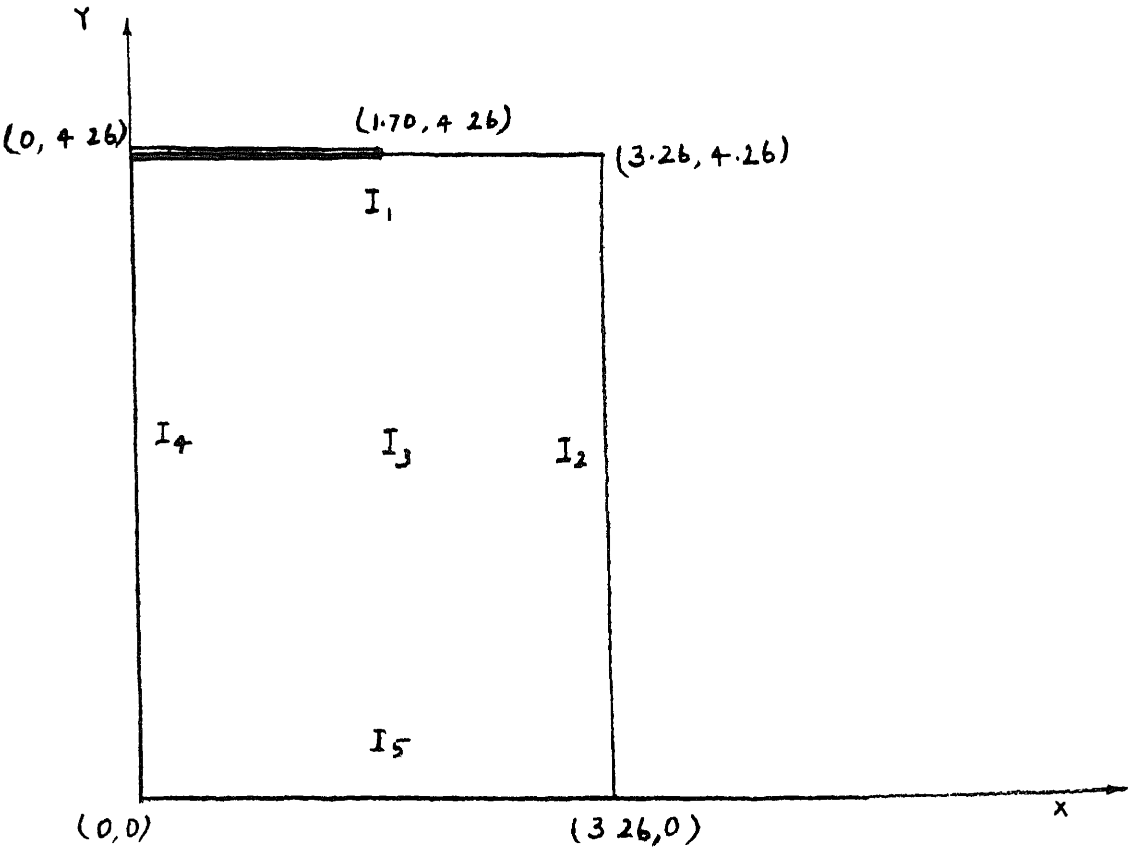


01.	Address with Floor no.	674, Pocket C, Sarita Vihar Ist floor
02.	Type of the building	Residential
03.	Type of the room	Bed room
04.	The day and time when the measurements are made	22-11-90, 10 10 am
05.	No. of windows (Mark w_1, w_2 ------ in Fig.)	1
06.	Window Height	90 cm
07.	Type of external shading device	Horizontal & Vertical overhangs
08.	Type of internal shading device	curtain
09.	Window glazing type	plain
10.	Normal time when the lights are switched on	5.15 p.m.
11.	Colour of internal finishing (Dark, Medium, Light)	Light

ILLUMINATION LEVEL IN LUX

Points	Co-ordinates	Light level with internal shading	Light level without internal shading	Remarks
I_1	(1 63, 4 01)	2	17	
I_2	(3·01, 2 13)	5	10	
I_3	(1 63, 2·13)	1	65	
I_4	(0 25, 2 13)	2	10	
I_5	(1 63, 0 25)	0	13	
O_1	-----		11,300	
O_2	-----		12,200	

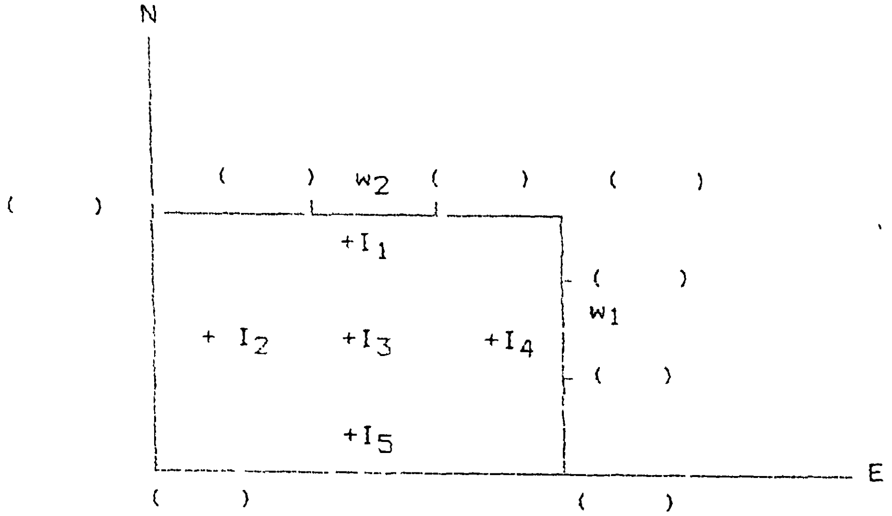
SPACE FOR THE FIGURE



BANGALORE

Data Sheet

ive a neat plan diagram of the room in a separate sheet with o-ordinate axes as shown below and mark the co-ordinates.

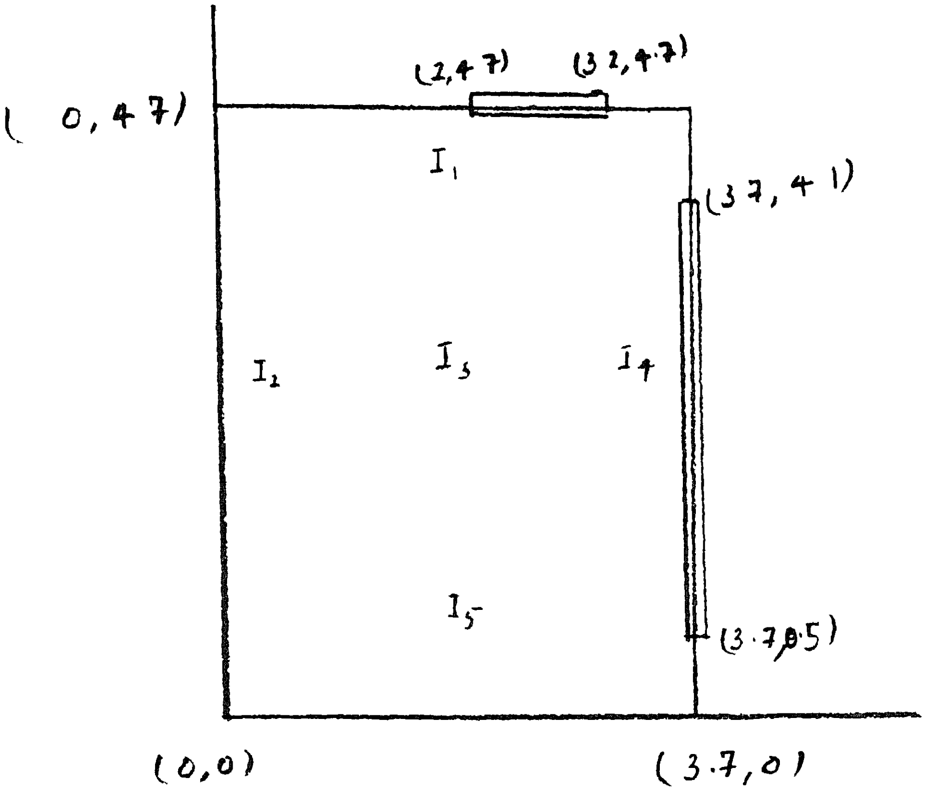


01.	Address with Floor no.	138, 13th A-Main 3rd Cross Mathikere Layout (GF)
02.	Type of the building	Residential
03.	Type of the room	Living Room
04.	The day and time when the measurements are made	26/12/92 3.30 PM
05.	No. of windows (Mark w_1, w_2 ------ in Fig.)	2
06.	Window Height	1.7 m
07.	Type of external shading device	Horizontal overhang
08.	Type of internal shading device	—
09.	Window glazing type	plane
10.	Normal time when the lights are switched on	6 pm
11.	Colour of internal finishing (Dark, Medium, Light)	light

ILLUMINATION LEVEL IN LUX

Points	Co-ordinates	Light level with internal shading	Light level without internal shading	Remarks
I_1	(1.85, 4.5)	—	1800	
I_2	(0.5, 2.35)	—	700	
I_3	(1.85, 2.35)	—	1200	
I_4	(3.5, 2.35)	—	5500	
I_5	(1.85, 0.5)	—	1050	
O_1	——		14,000	
O_2	——		14,500	

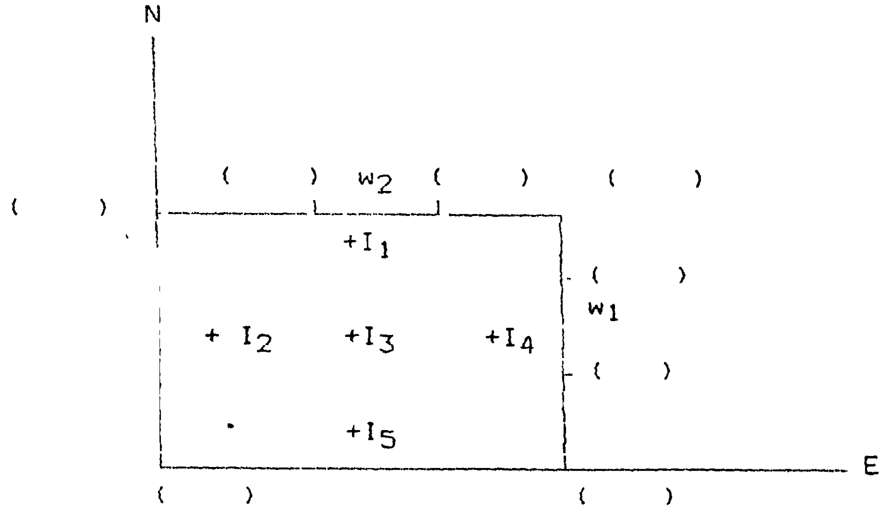
SPACE FOR THE FIGURE



BANGALORE

Data Sheet

Give a neat plan diagram of the room in a separate sheet with co-ordinate axes as shown below and mark the co-ordinates.

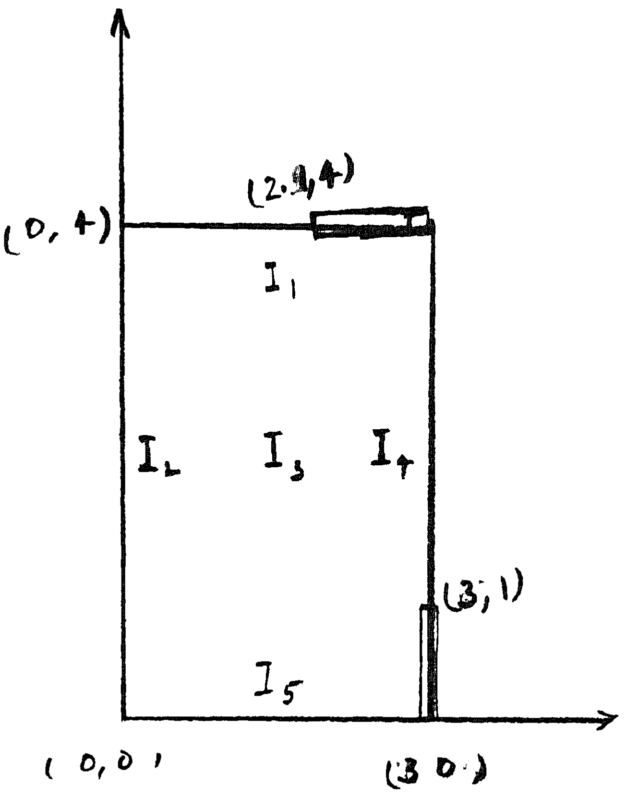


01.	Address with Floor no.	731, IX cross, 10A Main 2nd stage Indira Nagar (FF)
02.	Type of the building	Residential building
03.	Type of the room	Living
04.	The day and time when the measurements are made	19|12|92 11 AM
05.	No. of windows (Mark w_1, w_2 ------ in Fig.)	2
06.	Window Height	1·5 m
07.	Type of external shading device	—
08.	Type of internal shading device	—
09.	Window glazing type	plane
10.	Normal time when the lights are switched on	6 – 6·30 p m
11.	Colour of internal finishing (Dark, Medium, Light)	Light

ILLUMINATION LEVEL IN LUX

Points	Co-ordinates	Light level with internal shading	Light level without internal shading	Remarks
I_1	(1.5, 4)	—	400	
I_2	(0.5, 2)	—	50	
I_3	(1.5, 2)	—	180	
I_4	(2.5, 2)	—	180	
I_5	(1.5, 0.5)	—	550	
O_1	——		11000	
O_2	——		10500	

SPACE FOR THE FIGURE



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ROGRAM FOR THE DESIGN OF FENESTRATION FOR DAY-LIGHTING

ROGRAM DEVELOPED BY V. JAYADEVAN
ATA ENERGY RESEARCH INSTITUTE
- JOR BAGH, NEW DELHI, 110 003

    The Program is based on the C.B.R.I design method

    (1) The Window can be designed as either centrally located
    or corner located

    (2) The Window can be located either on longer wall
    or on shorter wall

    (3) The basis of design can be (a)Day-light factor at centre point
    or (b) Day-light factor at rear point

    The program also gives the number of cool daylight tubes for:
    1) Supplementary artificial lighting during day time.
    2) Providing the entire illumination artificially.


    ENTER YOUR CHOICE OF POSITION
    1 - FOR CENTRAL
    2 - FOR CORNER  ->1

    ENTER YOUR CHOICE OF LOCATION
    1 - FOR LONGER WALL
    2 - FOR SHORTER WALL  ->1



    ENTER THE DESIGN CRITERIA
    1 - FOR DAY-LIGHTFACTOR AT CENTRE POINT
    2 - FOR DAY-LIGHT FACTOR AT REAR POINT  ->1



    WHAT IS THE FLOOR AREA OF THE ROOM (Sq.M) ?  ->40



     INPUT THE DAY-LIGHT FACTOR FOR WHICH
     THE FENESTRATION DESIGN HAS TO BE MADE >  ->2



     ARE YOU DESIGNING FOR GROSS AREA (TOTAL AREA OF THE WINDOW)
     OR EFFECTIVE AREA ?
     ENTER YOUR CHOICE
     1 - FOR GROSS AREA      2 -FOR EFFECTIVE AREA  ->1
```

```
 ENTER THE TYPE OF SASHES USED
 FOR METTALIC   2 - FOR WOODEN  ->1


HERE ANY EXTERNAL OBSTRUCTION IN FRONT OF THE WINDOW [Y/N] y


HT OF THE OBSTRUCTION FROM WINDOW SILL (M) >5


ANCE OF THE OBSTRUCTION FROM THE WINDOW (M) >10




 FENESTRATION AREA SHOULD BE >  2.47 Sq.M


PLEMENTRY LIGHTING TO BE PROVIDED TO TAKE CARE
THE LOW-DAYLIGHT HOURS-->   2 (NUMBER(S) OF COOL DAYLIGHT FLOURESCENT TUBES)


BER OF COOL DAYLIGHT FLOURESCENT LAMPS REQUIRED
THE ENTIRE ILLUMINATION IS DONE ARTIFICIALLY -->   8


  Program Successfully Terminated*****
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